

Scientific narratives for the protein transition:

Will systemic change be possible?

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Summary

This dissertation investigates the concept of the protein transition (PT) which can be defined as the shift from unsustainable animal-based consumption and production patterns toward more sustainable alternative protein sources and production systems. Introduced in the scientific literature in the early 2000s, the concept has since attracted growing interest from policymakers, industry actors, and other stakeholders as a framework for addressing environmental, health, and ethical challenges associated with livestock production and consumption. Yet, despite its widespread use, the meaning(s) of the PT remains contested.

The thesis pursued three overarching goals: (1) to unpack the meanings and functions of the PT in relation to food system sustainability in scientific literature; (2) to examine the disciplinary contributions and perspectives to the PT, looking at how these disciplinary perspectives are integrated into a holistic vision of PT; and (3) to assess the options and solutions being advanced under the concept of the PT, as well as their coherence with the underlying systemic challenges at stake. By addressing these goals, the research seeks to move beyond fragmented disciplinary debates and provide a more comprehensive understanding of the PT as both a scientific and a socio-political phenomenon.

The research combines systematic literature review, bibliometric and text-mining analysis, and expert interviews to examine the PT across multiple dimensions and disciplines. Five complementary papers structure the analysis: a systematic review of the definitions and narratives of the PT (The Narrative Paper); a bibliometric analysis mapping PT debates in relation to livestock sustainability (The Shadow Paper); a disciplinary analysis of PT research communities (The Discipline Paper); a Restatement paper synthesizing various disciplinary insights (The Restatement Paper); and a critical assessment of proposed PT solutions (The Paradox Paper).

The findings of the PhD indicate that the PT is predominantly defined from a consumption-based perspective, emphasizing dietary changes, while issues of livestock sustainability are largely addressed within separate research communities. This separation limits dialogue between the PT and livestock sustainability debates. Although the PT represents a multidimensional and systemic challenge, knowledge remains fragmented across scientific disciplines, which often operate within their own epistemological and ontological frameworks. These different frameworks can generate potentially incompatible understandings of the protein transition, influencing both the assessment of interventions (e.g., advising for red meat consumption

reduction or implementing nudging strategies) and what is considered valid evidence. As a result, siloed disciplinary approaches foster parallel and often poorly integrated viewpoints that hinder system-wide solutions. Interventions that appear promising are therefore rarely tested against the broader food system, addressing symptoms rather than underlying structural causes and revealing a gap between intervention design and the complexity of real-world dynamics. Finally, the results highlight how power relations shape which narratives dominate, often privileging technology- and innovation-driven solutions over sufficiency-oriented or structural approaches.

The dissertation further examines how these competing narratives are embedded within broader meta-narratives, such as the growth-centric paradigm, and how power operates at the intersections of science, policy, and industry. It argues that fragmented knowledge production shapes not only the substance of debates but also the capacity for coordinated action in food system transitions. Building on this, the work advances the idea of transformative science, a vision of research that is both reflexive and politically engaged. It positions science-policy interfaces as key arenas for enabling structural change, underscoring that meaningful transformation requires science to contribute actively to democratic, sustainability-oriented decision-making.

By integrating analysis of narratives, disciplinary approaches, and structural dynamics, this research offers a multidimensional understanding of the protein transition. It emphasizes the interplay between scientific knowledge, institutional structures, and power relations in shaping pathways toward sustainable food system transformation.

The dissertation further discusses the coexistence and competition of narratives and their link to more meta-narrative such as the growth-centric paradigm as well as the power dynamics at the science-policy-industry interface, and the consequences of fragmented disciplinary perspectives in food system transitions.

Résumé

Cette thèse explore le concept de transition protéique (TP), défini comme le passage de modèles de production et de consommation non durables, fondés sur la surconsommation et la surproduction de produits d'origine animale, vers des sources de protéines alternatives plus durables. Introduit dans la littérature scientifique au début des années 2000, ce concept a suscité un intérêt croissant parmi les décideurs politiques, les acteurs économiques et d'autres parties prenantes, en tant que cadre d'analyse pour appréhender les enjeux environnementaux, sanitaires et éthiques liés à la production et à la consommation de protéines animales. Toutefois, malgré sa diffusion et son adoption étendues, la signification même de la transition protéique demeure sujette à débat et interprétation.

La thèse poursuit trois objectifs principaux : (1) Décomposer les significations et fonctions de la TP dans la littérature scientifique, en lien avec la durabilité des systèmes alimentaires; (2) Examiner les contributions et perspectives disciplinaires relatives à la TP, et la manière dont elles s'intègrent dans une vision holistique de celle-ci ; (3) Évaluer les options et solutions proposées dans le cadre de la TP, ainsi que leur cohérence avec les défis systémiques sous-jacents. En répondant à ces objectifs, la recherche cherche à dépasser les débats disciplinaires fragmentés et à offrir une compréhension plus globale de la TP, à la fois comme phénomène scientifique et sociopolitique.

La méthodologie combine revue systématique de la littérature, analyses bibliométriques et textuelles, et entretiens avec des experts, afin d'examiner la TP sous plusieurs dimensions et à travers diverses disciplines. Cinq articles complémentaires structurent l'analyse : une revue systématique des définitions et récits de la TP (The Narrative Paper) ; une analyse bibliométrique des débats sur la durabilité de l'élevage (The Shadow Paper), une analyse des communautés de recherche disciplinaires (The Discipline Paper), une synthèse interdisciplinaire (The Restatement Paper), et une évaluation critique des solutions proposées (The Paradox Paper).

Les résultats du doctorat montrent que la TP est majoritairement définie sous un angle centré sur la consommation, mettant l'accent sur les changements alimentaires, tandis que les questions de durabilité de l'élevage sont traitées par des communautés de recherche distinctes. Cette séparation limite le dialogue entre la TP et les débats sur la durabilité de l'élevage.

Bien que la TP constitue un défi systémique et multidimensionnel, les connaissances restent fragmentées entre disciplines scientifiques, chacune opérant selon ses propres cadres épistémologiques et ontologiques. Ces différences peuvent engendrer des compréhensions incompatibles de la TP, influençant à la fois l'évaluation des interventions (par exemple, des recommandations de réduction de la consommation de viande rouge ou des stratégies de nudging) et la définition de ce qui est considéré comme une preuve valide (évalué selon les standards de chacune des disciplines).

Ainsi, les approches cloisonnées favorisent des points de vue parallèles et peu intégrés, freinant l'élaboration de solutions globales. Les interventions jugées prometteuses sont rarement testées à l'échelle du système alimentaire, s'attaquant davantage aux symptômes qu'aux causes structurelles, révélant un décalage entre la conception des interventions et la complexité des dynamiques réelles.

Enfin, les résultats soulignent comment les rapports de pouvoir influencent la domination de certains récits, privilégiant souvent les solutions technologiques et axées sur l'innovation, au détriment d'approches fondées sur la sobriété ou la transformation structurelle.

La thèse examine également la manière dont ces récits concurrents s'inscrivent dans des méta-récits plus larges (comme le paradigme de la croissance), et comment le pouvoir opère à l'intersection entre science, politique et industrie. Elle soutient que la production de savoirs fragmentée façonne non seulement le contenu des débats, mais aussi la capacité d'action collective dans les transitions des systèmes alimentaires.

S'appuyant sur cette analyse, le travail propose une vision de la science transformatrice, c'est-à-dire une recherche à la fois réflexive et politiquement engagée. Il positionne les interfaces science-politique comme des espaces clés pour favoriser le changement structurel, soulignant qu'une transition de modèle exige que la science contribue activement à une prise de décision démocratique et orientée vers la durabilité.

En intégrant l'analyse des récits, des approches disciplinaires et des dynamiques structurelles, cette recherche offre une compréhension multidimensionnelle de la transition protéique. Elle met en lumière l'interaction entre connaissances scientifiques, structures institutionnelles et rapports de pouvoir dans la construction de trajectoires vers une transformation durable des systèmes alimentaires.

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Looking back on these five years of doctoral work, I realize how profoundly this journey has been both a personal and professional process. When I embarked on this path, I did not truly understand what it meant to “be a researcher”, nor did I grasp all that it entailed. With hindsight, I now understand that one does not begin as a researcher but gradually becomes one. It is a process that requires far more time, patience, and resilience than I could have imagined. One of the most important lessons I have learned is precisely this: to allow time to do its work, to trust the process, even in moments when I felt overwhelmed.

“Don’t worry, don’t hurry, trust the process”

To become a researcher is, of course, to learn how to conduct research: to write scientific articles, conceptualize, collect and analyze data, and develop a rigorous methodology. But it is also, perhaps above all, to learn to question oneself, to tolerate uncertainty, to accept criticism as an opportunity to grow, and to evolve in an ever-shifting emotional and intellectual landscape. This path has been demanding, sometimes even daunting, but profoundly formative.

For me, a thesis was never simply a piece of work; it was a deep commitment. With that commitment came both perseverance and letting go, but also the constant presence of a project that sometimes weighed heavily, yet also inspired, sustained, and occasionally even exhilarated me. Looking back, especially on the beginning of the process, it resembled a long fog, punctuated by rare but luminous moments of clarity.

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"Because without you it would have been impossible, and without me it would have been different."

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Outline of the dissertation

This PhD is structured around seven main chapters. **Chapter 1 (Introduction chapter)** introduces and situates the protein transition as part of a broader food system transition. It delineates how the concept emerged, how it is approach from various disciplinary perspectives and also touches upon transition and transformative change theories. **Chapter 2 (Objectives, scope and posture)** defines the key delineations of the research, including the adopted epistemological posture, the scope of the study, its objectives, and the envisioned contributions. **Chapter 3 (Results)** presents the core findings of the PhD. Each subchapter corresponds to one of the five research papers included in this PhD with main results, key contributions and limitations summarized. **Chapter 4 (The Reflection chapter)** provides a general discussion that synthesizes insights across the papers, while **Chapter 5 (Momentum for transformative change)** offers a forward-looking reflection on the role of science in pursuing transformative change. **Chapter 6 (Personal journey)** is a personal reflection on the PhD journey, and **Chapter 7 (Conclusion)** concludes the dissertation. All supplementary data supporting this publication are publicly accessible on **Zenodo** and can also be accessed via the following repository: <https://github.com/ODuluins/Scientific-narratives-for-the-protein-transition>.

Chapter 1: Introduction

Food systems in crisis

Contemporary food systems¹ are increasingly described as being in a state of crisis. On the one hand, they are failing to ensure equitable and healthy nutrition for all: about 8% of the global population remains undernourished in 2024 (FAO, 2024a), while overweight and obesity affect over two billion people worldwide (WHO, 2025). On the other hand, the ways in which food is currently produced, processed, and consumed are driving profound ecological degradation. The food sector is a leading contributor to greenhouse gas emissions, biodiversity loss, land-use change, freshwater depletion, and nutrient pollution (Rockström et al., 2009; Willett et al., 2019). These pressures are compounded by social and economic challenges, including precarious livelihoods for farmers and food workers, global inequalities in access to resources, and growing vulnerabilities in the face of climate change and geopolitical disruptions (Benton, 2020; Herrero et al., 2009; Raworth, 2017). Together, these intersecting health, environmental, and social crises underscore that food systems are no longer simply a matter of increasing productivity and feeding people but have become central to broader debates on planetary sustainability and human well-being (Benton & Bailey, 2019).

Within these systemic crises, the role of livestock production and meat consumption has become particularly salient (Herzon et al., 2023). Livestock systems epitomize many of the tensions at the heart of food systems: they provide key sources of nutrition and livelihoods, yet they also account for disproportionate environmental burdens and raise ethical concerns around animal welfare (Herrero et al., 2023). As such, rethinking how meat is produced, consumed, and valued have gained momentum as an entry point for addressing the broader crisis of food systems.

Livestock beyond limits: Ecological and social boundaries

Since the turn of the century, livestock has come under growing scrutiny for its role in food systems, with mounting evidence linking its production to substantial environmental impacts (Alkemade et al., 2013; Herrero et al., 2015; Pelletier & Tyedmers, 2010). The publication of the Food and Agriculture Organization's (FAO) report 'Livestock's Long Shadow' played a

¹ The terms *food system* and *food systems* are used differently in the literature. *Food system* (singular) typically refers to the global, interconnected network of food production, distribution, and consumption, emphasizing overarching dynamics. *Food systems* (plural) highlights the diversity of regional, national, and local systems, recognizing variation in practices, governance, and socio-cultural contexts. In this paper, we use both forms strategically based on these definitions.

major role in highlighting these environmental issues (Steinfeld et al., 2006). The report states that the livestock sector is one of the three sectors that contribute most to human-induced environmental problems globally. Environmental damages include greenhouse gas emissions (notably methane and nitrous oxide) from enteric fermentation and manure management, water and air pollution through nutrient leakage, and depletion of water and other scarce resources (Gerber et al., 2013; Steinfeld et al., 2006). Moreover, some indirect effects arise from pasture management and the production of feed crops, e.g., deforestation through the production of soybeans (J. Karlsson et al., 2021) or competition for land that could alternatively be used for food crop production (J. Karlsson & Rööös, 2019). Building on the planetary boundaries framework introduced by Rockström et al. (2009), the livestock sector emerges as a major contributor to several critical environmental pressures. It accounts for approximately 31% of food system greenhouse gas emissions (Ritchie, 2019), uses an estimated 41% of total agricultural water (both blue² and green³) for feed production (Heinke et al., 2020), and occupies 77% of global agricultural land—mostly for grazing or feed crops (Ritchie & Roser, 2019). In addition, it plays a key role in driving biodiversity loss and nutrient-driven water pollution (Li et al., 2022; McClelland et al., 2023; Yang et al., 2020), despite supplying only 18% of the world's calories.

This evidence has led scholars to argue that the livestock sector is operating out of the Safe Operating Space (SOS), a concept used to assess sustainability in terms of ecological, social, and health thresholds (Bowles et al., 2019; Buckwell & Nadeu, 2018). In their report, Buckwell and Nadeu (2018) define the SOS as an area *"between the lower boundaries defined by the level of livestock production and consumption which offer sufficient health, cultural, environmental, social and psychic benefits of farmed animals, and the upper boundaries defined by the sustainable thresholds for the negative impacts on health and environment and acceptable animal welfare"*. They show that the European Union (EU) (Box 1) livestock production and consumption are out of balance: emissions and nutrient flows surpass ecological limits, animal numbers exceed what is needed for land maintenance, and meat consumption overshoots national dietary guidelines, often by more than double in many Member States (Buckwell & Nadeu, 2018).

² Blue water refers to the fresh surface and groundwater available in rivers, lakes, reservoirs, and aquifers that can be withdrawn for irrigation, industrial use, and domestic purposes.

³ Green water is the moisture stored in soil that originates from rainfall and is available to plants through root uptake. It is not accessible for withdrawal but is crucial for rainfed agriculture and natural ecosystems.

Alongside environmental concerns, the ethical and public health dimensions of intensive livestock production systems have drawn increasing scrutiny. Disease outbreaks such as Bovine Spongiform Encephalopathy (BSE) and swine fever have underscored the vulnerability of industrial livestock production to food safety threats and zoonotic spillovers (Marchant-Forde & Boyle, 2020). These crises have highlighted the limitations and potential drawbacks of livestock intensive production systems (Layton et al., 2017). Animal welfare has likewise emerged as a major concern, particularly regarding how animals are bred, fed, transported, and slaughtered (Buckwell & Nadeu, 2018). More specifically, indoor systems marked by overcrowding, stress, and poor living conditions, are especially criticized for their lower welfare standards and for facilitating the rapid transmission of infectious diseases (El Sabry et al., 2023; Gomes et al., 2014; Proudfoot & Habing, 2015; Vos, 2000).

Box 1: Geographical scope of the PhD

This PhD has two main scales of analysis (see section Scope p.20). At the Organization for Economic Cooperation and Development (OECD) level, the focus lies on high-income countries where historically elevated levels of animal protein consumption make livestock-related challenges particularly salient. At the European level, the PhD narrows in on the EU, where production and consumption patterns, alongside the distinctive governance structure, render it a critical setting for examining the dynamics of the protein transition. Together, these two levels of analysis help capture both the general challenges faced by high-income food systems which make the protein transition particularly relevant in these contexts, and the specific institutional and political dynamics of the European Union. We also recognize that different geographical settings come with distinct production and consumption challenges, meaning that the dynamics described here may not directly apply to other regional contexts. For example, in some regions of the world, and even within specific population groups in the EU, insufficient protein intake remains a pressing nutritional concern, shifting the focus from substitution or reduction toward improving accessibility and affordability (Gatto et al., 2023).

These ethical and health concerns intersect with dietary risks associated with processed and red meats consumption. Frequent intake of these products has been linked to an increased risk of colorectal cancer (Razmaité et al., 2020), cardiovascular disease (G.-C. Chen et al., 2013; Craig et al., 2021) and premature mortality (Etemadi et al., 2017; Pan et al., 2012; Sinha et al., 2009), although the strength of causal links is still debated (Händel et al., 2021; Nouri-Majd et al., 2022).

Conversely, while limitations in epidemiological research warrant caution, diets rich in legumes, nuts, dairy, and plant-based proteins are generally associated to lower risks of chronic diseases, including cardiovascular disease, type-2 diabetes, and some cancers (Soedamah-Muthu & de Goede, 2018).

Against this backdrop, initiatives to define sustainable and healthy diets have gained momentum. Influential frameworks such as the Eat-Lancet Commission's report and WWF's Livewell guidelines have helped translate complex environmental and health data into actionable dietary targets (Macdiarmid et al., 2011; Willett et al., 2019). Both emphasize the need to reduce red meat consumption substantially while boosting the intake of plant-based foods, not only to meet climate targets but also to support population health.

Recent empirical studies further support these integrated dietary transitions. Plant-forward or reduced-meat diets have been shown to significantly lower greenhouse gas emissions, water and land use, and the risk of non-communicable diseases (Bunge et al., 2024; H. Chen et al., 2024; Poore & Nemecek, 2018; Scarborough et al., 2023). Together, these findings have reinforced calls for systemic dietary change, particularly around protein-rich foods⁴ consumption, as a way to confront both environmental degradation and public health challenges. This has brought protein to the centre of sustainability debates and set the stage for the emerging concept of the protein transition.

The emergence of the protein transition as a concept

While environmental, health, and ethical concerns linked to (intensive) livestock farming were not new, the framing of these issues under the label of a "protein transition" represented a novel development. I first encountered the term *protein transition* while working on my first paper as a PhD student, "*Economic Implications of a Protein Transition*" (Duluins et al., 2022), which investigated how such a transition would affect the economic performance of dairy and beef farms in Wallonia (Belgium). Linking the livestock sector to the protein transition was particularly innovative, as most of the literature I reviewed was either focusing on livestock production challenges and strategies to improve their sustainability or discussing the protein transition primarily as a dietary shift away from meat and other animal-based foods. This reframing opens up new ways of thinking about interventions, policies, and research agendas.

⁴ A food is generally considered protein-rich if protein makes up a substantial part of its macronutrient profile, often above 10–15% of total calories, but definitions can vary depending on dietary guidelines.

One of the earliest uses of the concept can be found in the book 'Sustainable Protein Production and Consumption: Pigs or Peas?' by Aiking et al. (2006), a major output of the PROFETAS project⁵. This research project aimed to investigate the possibility of substituting animal-based protein sources with plant-based options in the food chain. The term quickly became a buzzword in both academic and policy debates, gaining traction as a way of linking concerns about food, health, and sustainability (Aiking, 2014; Hundscheid et al., 2024; Steinfeld et al., 2006). For instance, the Netherlands, Denmark, and Flanders (Belgium) have launched government-led protein transition strategies, and the European Union has progressively integrated the issue into its policy agenda. In 2018, the European Commission published a report highlighting the potential of plant proteins and the need to boost domestic feed (and food) production (European Commission, 2018). In 2022, the European Parliament called for a comprehensive EU protein strategy to reduce feed import dependency and enhance food security (European Parliament, 2023). By 2023–2024, the European Commission released factsheets highlighting the EU's ongoing protein deficit: despite producing 64 million tons of crude protein⁶, an additional 19 were still imported. These documents also outlined a range of responses, including CAP interventions, national strategies, and research initiatives aimed at increasing local production (European Commission, 2024).

Despite its rapid uptake, the meaning of the protein transition remains contested (Béné & Lundy, 2023). Is it about shifting production practices, developing novel protein sources, reshaping consumer behavior, or more broadly rethinking how food systems organize the production and consumption of protein-rich foods? (Duluins et al., 2022; Hundscheid et al., 2024; Jain et al., 2024; Simon, Hijbeek, et al., 2024)

Much of the momentum around the concept has come from industry actors, who have embraced it as a frame for innovation (Guthman et al., 2022; Lurie-Luke, 2024). A growing range of alternative protein-rich foods is being developed and marketed as technological solutions capable of simultaneously improving human health, addressing global food security, reducing environmental harms, and enhancing animal welfare (Lurie-Luke, 2024). These products are often positioned as safer and more ethically responsible alternatives to conventional livestock

⁵ Protein Foods, Environment, Technology, And Society (PROFETAS). Website link: <https://www.profetas.nl/PROFETAS%20links.htm>

⁶ Crude protein refers to an estimate of the total protein content in a sample, typically calculated from its nitrogen content using a standard conversion factor (commonly 6.25). This method assumes that most nitrogen in the material is present in amino acids, the building blocks of proteins. However, the measure may also include non-protein nitrogen compounds (such as urea or nitrates), meaning that crude protein values can overestimate the actual amount of proteins available for nutrition.

farming, while promising to replicate the taste and sensory appeal of animal-based foods (Sexton et al., 2019). However, the legitimacy of these claims remains under scrutiny. It has been shown that different actors may evaluate the evidence and potential impacts differently, reflecting their specific interests and priorities, thereby influencing both public perception and policy responses (Sievert et al., 2022; Wood et al., 2025).

At the same time, broader questions arise regarding the legitimacy of the proposed “protein transition” itself. Who decides that such a transition is necessary, and on what grounds? Environmental organizations, for instance, have been vocal advocates of reducing industrial livestock production because of its substantial contribution to greenhouse gas emissions, land use pressures, and biodiversity loss (iPES Food, 2022). For these groups, a shift toward alternative proteins is framed as an urgent ecological necessity. Farmers and livestock industry representatives, on the other hand, may distrust these claims, viewing the protein transition as a threat to rural livelihoods, cultural traditions, and national food sovereignty (Katz-Rosene et al., 2023; Koole, 2022). Consumers, meanwhile, may remain skeptical about the safety, naturalness, or desirability of highly engineered protein products. As a result, claims surrounding the protein transition are contested, involving struggles over who holds authority to define the problem, who benefits from the proposed solutions, and who bears the costs of change (Béné & Lundy, 2023; iPES Food, 2022; Katz-Rosene et al., 2023).

The diversity of interpretations of what constitutes a protein transition is crucial to consider, as different understandings imply different transition pathways, which in turn may produce very different environmental, nutritional, and socio-economic outcomes (Kiel et al., 2026). For instance, questions remain about whether marginal reductions in meat consumption in the EU can meaningfully influence the dominant global food production system, given that current patterns of livestock production and consumption are deeply embedded in political, economic, and cultural structures (Resare Sahlin, 2024; SAPEA, 2023). For example, there are concerns that reducing meat production within the EU could simply shift production to low-income countries with weaker environmental and animal welfare standards, leading to increased imports and potentially offsetting the intended benefits.

Finally, the term *protein transition* is not only a scientific concept, but also a politically and socially charged one. Livestock, meat and other animal-based foods are highly charged topics, intertwined with cultural identity, economic interests, and power structures (Chatterjee & Subramaniam, 2021; Sievert et al., 2025). Referring to a *protein transition* allows for discussions

on reducing meat consumption and promoting alternative proteins without directly confronting the meat sector. However, this flexibility also carries risks: while it can act as a Trojan horse to foster broader rethinking of food systems, the concept can just as easily be co-opted to advance narrower or conflicting agendas.

The protein transition as part of a broader food system transition

The protein transition can be seen as an integral part of a wider food system transition (Juri et al., 2024), contributing to the overarching goal of “providing enough nutritious food to feed the world in an environmentally sustainable way while facilitating fair and equitable livelihoods, social justice, and respect for cultural values” (FAO, 2018). Moreover, it aligns with and supports the realization of multiple Sustainable Development Goals (SDG), particularly those related to zero hunger (SDG 2), good health and well-being (SDG 3), responsible consumption and production (SDG 12), climate action (SDG 13), and life on land (SDG 15) (Aiking & de Boer, 2020; Herrero et al., 2020; Sogari et al., 2023). Yet, some scholars have questioned the sudden centrality of “protein” as an organizing concept. They argue that people do not consume proteins as such, but food, which is embedded in broader dietary patterns, cultural practices, and socio-economic relations (Leroy, Beal, et al., 2022; Weindl et al., 2020). From this perspective, they argue that an exclusive focus on proteins narrows debates about sustainability, obscuring systemic issues such as overconsumption, inequitable access, and the political economy of food systems.

Still, even if the notion of “protein” may at times mask specific agendas or oversimplify complex realities, the protein transition remains a revealing lens for understanding the deeper structural challenges that characterize food system transformations. Livestock, in particular, plays a pivotal role in these dynamics, standing at the heart of current environmental, economic, and social disruptions. At its core, the protein transition highlights persistent imbalances rooted in long-standing path dependencies that create multiple lock-ins, that is deeply embedded agricultural and dietary practices that are structurally difficult to change (Clapp, 2025; Clapp et al., 2025). For instance, EU livestock farming systems are both directly and indirectly subsidized, particularly through the CAP, which has historically favored animal production over plant-based alternatives (Guyomard et al., 2021; Kortleve et al., 2024). These economic incentives, alongside investments in infrastructure, institutional frameworks, and trade agreements, have reinforced a production model that is resistant to change, even when alternatives are available (Vallone & Lambin, 2023).

Such lock-ins help explain the persistence of systemic imbalances such as the over- or under-consumption of animal protein foods (Simon, Hijbeek, et al., 2024), and the geographic concentration of livestock and manure-related pollution in certain regions (Wang et al., 2018). Shifting from this unbalanced status quo to an alternative equilibrium is inherently complex and risky, as altering foundational elements of the system can trigger wide-ranging disruptions. For example, reducing animal-based product consumption in Europe would have far-reaching consequences not only for the livestock sector, but also for feed production systems, labor, and global trade dynamics (Hristov et al., 2024; Rieger et al., 2023). Similarly, halting soybean imports, currently filling critical gaps in the EU feed supply, would severely affect livestock production, particularly in monogastric sectors such as pork and poultry and affect commercial equilibrium of South American countries (J. Karlsson et al., 2021). Such path dependencies highlight the structural complexity of transitioning to more sustainable food systems (Zander et al., 2016). Because food systems are deeply interconnected, any significant change in one component will have ripple effects across others, underscoring the need for system-wide consideration (Hristov et al., 2024; Rieger et al., 2023).

As with other food system transition efforts, the protein transition encompasses both production and consumption dimensions, and the complex value chains that connect them (Geibel & Freund, 2023; Prag & Henriksen, 2020; Rieger et al., 2023). Actors across the supply chain, from farmers and processors to retailers and marketers, play critical roles in shaping the availability, affordability, and appeal of protein products (Koole, 2022; van Vugt & Nadeu, 2025). Yet, research and policy tend to focus on consumer behavior or farm-level changes, often overlooking the influence of midstream actors such as retailers, who significantly shape food environments through pricing strategies, marketing, and product placement (Clapp et al., 2025; Sievert et al., 2024, 2025). Moreover, the protein transition operates across multiple, interconnected geographical and organizational scales, from local and regional contexts to global dynamics, and spans diverse decision-making arenas, from individual farm business plans to regional governance and EU-level policies (Hundscheid et al., 2022; Koole, 2022).

Finally, justice and equity are central considerations in the protein transition, raising crucial questions about who benefits from changes in protein production and consumption, who bears the associated costs, and whose perspectives and interests are included or excluded (de Bruin et al., 2025; Stirling, 2015). These concerns are particularly salient given the global nature of protein (and food) systems, where interventions in high-income countries may have effects on

producers and consumers in low- and middle-income countries (Barreiro Hurlé et al., 2021). Such dynamics reflect broader patterns observed in other socio-technical transitions, such as the shift from fossil fuels to renewable energy, where competing visions, entrenched power relations, and differential access to resources strongly influence whose interests are prioritized and which pathways gain legitimacy (Baudish et al., 2024; Béné et al., 2019; Kaljonen et al., 2021).

In this context, the protein transition offers a valuable lens for examining the broader dynamics of food systems transition. Taken together, these dynamics underscore that the protein transition is not merely a matter of producing or consuming alternative proteins, but a complex, multi-level process that navigates competing interests, power asymmetries, and systemic interdependencies to achieve meaningful, sustainable, and equitable change.

Various disciplinary perspectives

Reflecting the complexity of the protein transition, research spans a wide range of academic disciplines, each focusing on different dimensions of the food system. Among others, environmental scientists and ecologists investigate the environmental impacts of different protein sources, assessing factors such as greenhouse gas emissions, land use, and resource efficiency (M. Clark & Tilman, 2017; Detzel et al., 2022; Smetana, Bhatia, et al., 2023). Nutritionists and dietitians analyze the health implications and nutritional profiles of alternative proteins, considering their potential to meet dietary needs and improve public health outcomes (Chalupa-Krebzdak et al., 2018; de las Heras-Delgado et al., 2023; Tay et al., 2023). Consumer behavior and psychology researchers explore factors influencing acceptance and adoption of new protein products, examining attitudes, cultural norms, and willingness to change dietary habits (Amato et al., 2023; Hartmann & Siegrist, 2017a; Onwezen et al., 2021, 2022; Siddiqui et al., 2022). Food technologists and engineers work on developing innovative production methods for alternative proteins, such as cultured meat and fermentation-based products, optimizing scalability, safety, and cost-efficiency (Canti et al., 2024; Gong et al., 2023; Hadi & Brightwell, 2021). Meanwhile, political economists and sociologists examine the power relations and institutional structures underlying the protein system, analyzing the roles of corporate interests, lobbying, and public-private partnerships in shaping market dynamics and narratives around proteins (Guthman et al., 2022; Hedberg, 2023; Howard, 2022).

Each of these discipline approaches the protein transition from distinct ontological and epistemological positions, which fundamentally shape what is considered real, relevant, and knowable within that field (Cleaver & Tom, 2008). Ontology concerns the nature of the phenomena under study, what exists and how it is categorized, while epistemology relates to the ways of knowing, including the methods, evidence, and standards of justification deemed valid (Moon & Blackman, 2014). Environmental scientists typically adopt a realist ontology, assuming that a single, objective reality exists independently of human perception, and pair this with an objectivist epistemology, privileging quantitative methods and empirical measurement. In contrast, many social scientists operate from a relativist ontology, understanding social phenomena as multiple, context-dependent realities shaped by human interpretation, and a constructivist or subjectivist epistemology, relying on qualitative methods to explore power relations, institutional arrangements, and cultural meanings (Moon & Blackman, 2014).

These disciplinary ontologies and epistemologies can produce internally coherent but potentially incompatible understandings of the protein transition. First, they influence the evaluation of feasibility of different interventions: solutions that appear optimal from one disciplinary perspective may be challenged when assessed against another's criteria. For example, an intervention deemed environmentally optimal may be culturally unacceptable, a nutritionally beneficial solution may be economically unfeasible, and a technically scalable innovation may exacerbate social inequities. Second, they shape the validation of facts, reflecting differences in what each discipline recognizes as credible evidence or legitimate knowledge. Each discipline operates "within the truth" of its own framework, defining problems, solutions, and success criteria according to its own epistemic standards. Such divergences underscore the challenge of integrating knowledge across disciplines and highlight the risk of a "dialogue of the deaf", wherein researchers inadvertently talk past one another because their underlying assumptions about what constitutes valid knowledge and relevant phenomena differ or because their conclusions conflict when combined (van Eeten, 1999).

Despite the richness of disciplinary insights, a systemic and interdisciplinary⁷ perspective explicitly considering interactions, feedback, and trade-offs across social, ecological, technological, and economic dimensions is largely absent in current protein transition research.

⁷ In this PhD, interdisciplinarity refers to an approach to research, learning, or problem-solving that integrates knowledge, methods, and perspectives from two or more academic disciplines to address a question, issue, or phenomenon that cannot be fully understood through a single disciplinary lens.

From innovation to transformative change

The study of socio-technical transitions has evolved to understand how complex systems, such as energy, transport, and food systems, change over time. One of the earliest and most influential frameworks in this field is the Multi-Level Perspective (MLP) developed by Geels (2002, 2005) in response to a commission by the Dutch government to design a framework for supporting sustainable transitions. At its origins, the MLP conceptualizes technological transitions as the outcome of interactions across three analytical levels (Figure 1): niche innovations, where novel technologies or practices emerge; the socio-technical regime, representing the dominant structures, practices, and rules that stabilize the system; and the socio-technical landscape, encompassing broader contextual pressures such as cultural norms, political dynamics, and macroeconomic trends (Geels, 2002, 2005). Central to this framework is the notion of a dominant regime, which both constrains and channels innovations. Transitions occur when niche innovations align with pressures at the landscape level, opening possibilities for regime shifts. The MLP also allows to consider the significance of the degree of change: incremental innovations typically emerge within regimes, reflecting adaptation, whereas radical innovations often develop in protected niches and can trigger profound reconfigurations of socio-technical systems (Geels, 2002).

While groundbreaking in linking technological innovation to systemic change, the MLP has faced multiple critiques. It has been criticized for its limited attention to the roles of political institutions and power dynamics, the limited attention to regime-to-regime interactions, and the residual role of the landscape (Geels, 2019). Recent external shocks illustrate how sudden landscape pressures can accelerate or redirect transitions. For example, the rise of populist political movements such as the election of Donald Trump reshaped energy and environmental policy in the United States, creating uncertainties for renewable energy transitions (Carlin, 2024). Similarly, the war in Ukraine disrupted global energy and food markets, exposing vulnerabilities in entrenched systems and prompting rapid adaptation at multiple levels (Zhou et al., 2023). These examples show that external shocks, while often unpredictable, can destabilize incumbent regimes and create windows for systemic change. Scholars have also noted the tendency of the MLP to focus narrowly on technological aspects, often underestimating the societal and cultural dimensions of transitions (Geels, 2019; Genus & Coles, 2008; Pel et al., 2023). Nevertheless, the

framework has continued to evolve, being adapted, tested, and widely applied to study socio-technical transitions across multiple sectors (Geels, 2019).

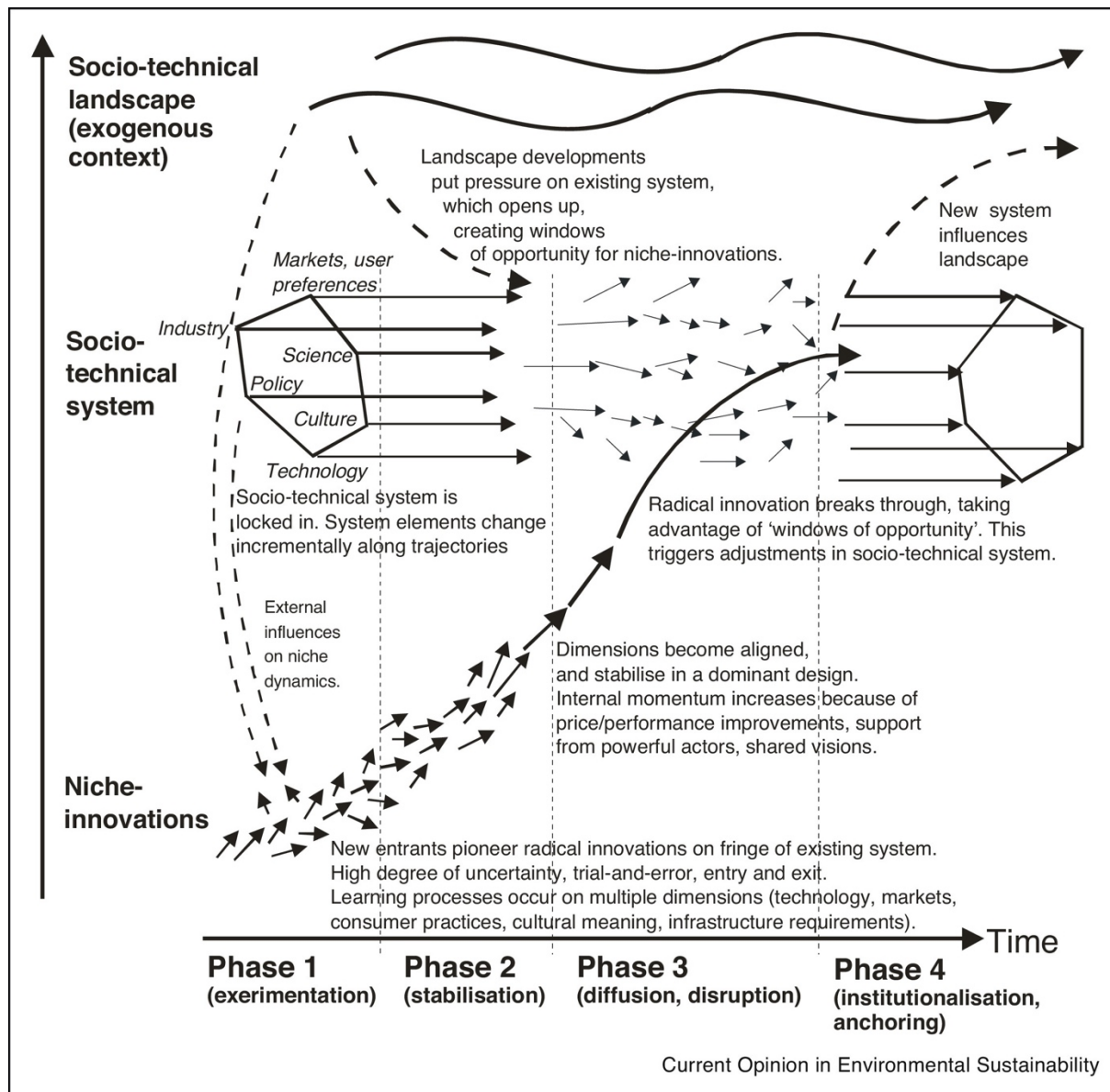


Figure 1: Schematic representation of the Multi-Level Perspective (MLP), where the vertical axis distinguishes niche innovations, the socio-technical regime, and the broader landscape, and the horizontal axis represents time and the dynamics of transitions (Source: Geels (2019))

Building on these critiques, subsequent refinements have sought to address some of the framework's blind spots. One prominent example is Geels and Schot's (2007) differentiation of transition pathways, which responds to concerns about the MLP's bottom-up bias. By varying the timing and nature of multi-level interactions, they identified four archetypal pathways that can be ranked according to the depth of deliberate restructuration they require:

1. **Technological substitution pathway:** In this pathway, competitive niche innovations provide a quick and effective replacement for problematic regime practices. Innovations generally align with the deeper structures of the regime, and incumbents can adopt them as a means of stabilizing the system, while making only limited adjustments to the regime components.
2. **Transformation:** Transformation occurs when landscape pressures destabilize a regime, but fully developed alternatives are lacking. In such cases, the regime responds by investing in research, experimentation, and incremental restructuring. This pathway involves co-evolutionary processes: small-scale pilots, growing learning communities, and gradual institutional adjustments. Political and economic struggles often shape the trajectory, as incumbents may attempt to steer innovations in ways that preserve their interests.
3. **Reconfiguration:** The reconfiguration pathway involves the gradual integration of multiple, already developed innovations as add-ons to the existing regime. Rather than wholesale replacement, these innovations reshape the system incrementally by altering infrastructures, incentive structures, and information flows. The process is often uneven, as some innovations achieve alignment while others remain marginal due to cultural or institutional resistance.
4. **De-alignment and re-alignment:** This pathway emerges when landscape shocks erode confidence in an incumbent regime, triggering systemic destabilization and opening space for experimentation with multiple alternatives. In such contexts, regime actors and new entrants contest meanings, institutions, and alliances as they search for viable replacements. Competing innovations vie for dominance until one consolidates into a new socio-technical order.

These pathways underscore that transitions are not uniform and that multiple pathways may unfold simultaneously or sequentially, producing divergent outcomes. For example, according to a study by Kiel et al. (2026), alternative proteins are part of a reconfiguration pathway because they consist of multiple developed innovations that can be integrated into the existing food system as add-ons targeting specific consumer groups (Kiel et al., 2026). Regime actors must adapt existing structures and practices to accommodate these innovations, resulting in partial restructuring rather than full systemic replacement (Kiel et al., 2026).

Another framework widely used in innovations studies, economics and technology management, is the S-curve framework describing how new technologies, practices, or products are adopted over time. The “S” shape shows how new technologies or practices emerge slowly in niche contexts, accelerate as they gain legitimacy and wider uptake, and eventually stabilize or saturate as they mature (Samoggia et al., 2025). This pattern highlights the non-linear nature of transitions, where growth often follows a slow-fast-slow trajectory (Figure 2). While useful for understanding how innovations scale, the framework mainly emphasizes build-up processes and pays less attention to the decline or phase-out of incumbent systems. The X-curve addresses this gap by explicitly integrating both build-up (innovation and emergence) and breakdown (decline and exnovation) processes, highlighting that transformation involves simultaneous creation (ascending curve, Figure 2) and destruction (descending curve, Figure 2) (Hebinck et al., 2022). The X-curve is particularly valuable for capturing non-linear and overlapping transitions, which the MLP describes more abstractly through level interactions (Hebinck et al., 2022).

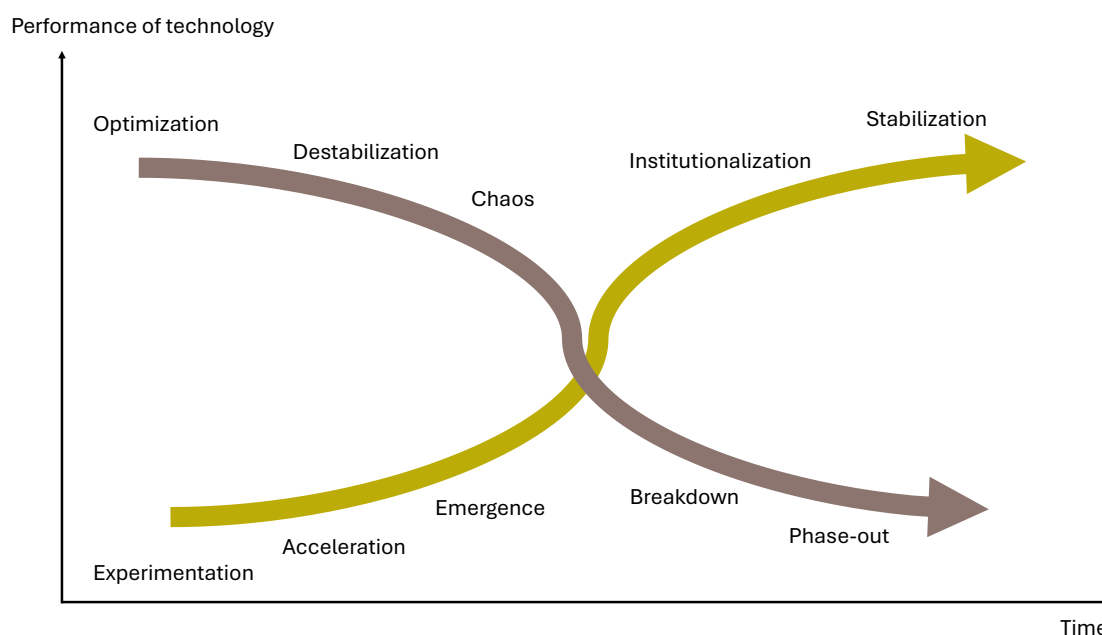


Figure 2: The S- and X-curves. The from the bottom to the top illustrates the S-curve, while the combination of arrows depicts the X-curve.

Applied to the protein transition, these frameworks help understand not only potential transition pathways, but also the temporal and structural dynamics shaping the transition. This PhD applies these frameworks to examine the interaction between niche innovations (e.g., novel alternative proteins), the incumbent regime (e.g., European livestock production systems), and the

landscape (e.g., climate pressures, consumer trends), assessing whether current transition pathways are oriented toward adaptive adjustments (with for example the technological substitution pathway) or more profound reconfiguration of the food system (with, for example, the de-alignment, re-alignment pathway). Moreover, the PhD also considers phase-out dynamics, recognizing that systemic transformation implies not only the scaling of new practices or technologies but also the managed decline and eventual replacement of unsustainable practices and technologies.

Frameworks for studying socio-technical transitions, such as the MLP, primarily originate from innovation and technology studies. Complementing this perspective, the literature on transformative change addresses deeper, system-wide shifts that can fundamentally alter values, norms, and governance arrangements.

Transformative change has emerged across multiple strands of scholarship. For example, in biodiversity and conservation governance, transformative change has been defined as “a fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values” (IPBES, 2019). In governance and public policy, it refers to fundamental shifts in institutions, policies, and governance arrangements necessary to address complex sustainability challenges (e.g., Termeer et al., 2024). In the climate change adaptation literature, transformative change is contrasted with incremental adjustments and involves altering structures, systems, or values to respond to long-term climate risks (e.g., Kates et al., 2012). Finally, in development studies, it is linked to systemic shifts in economies and societies that enable progress toward the SDGs, climate targets, and just transitions (e.g., Anderson & Leach, 2019). Across these diverse strands, transformative change is consistently understood as deep, system-wide shifts that alter underlying structures, values, and institutions, aiming to create more sustainable, resilient, and equitable systems.

In this PhD, we recognize that transition pathways differ in both depth and scope. Rather than adhering to a single framework, we draw selectively on the transformative change literature and the MLP, adapting their terminology and concepts to suit our analysis.

Chapter 2: Objectives, scope and posture

This thesis explores the concept of the protein transition as a key steppingstone for addressing pressing global challenges such as reducing greenhouse gas emissions, mitigating biodiversity loss, and improving global food security while acknowledging that it represents only one component of a broader transition of food systems toward sustainability and equity (Aiking & de Boer, 2020).

The protein transition involves complex systemic changes in how proteins are produced and consumed, with many possible directions and uncertain outcomes (Bai et al., 2016). These uncertainties arise partly from relatively recent emergence of the protein transition as an analytical concept in the early 21st century (Aiking et al., 2006) which provides a framework for studying these shifts rather than an established or universally agree-upon concept.

This evolving and still-evolving concept offers a valuable opportunity not only to explore it with analytical openness and without the constraints of entrenched perspectives, but also to critically examine and influence the narratives, assumptions, and proposed solutions of the protein transition. By doing so, this PhD aims to contribute to defining the concept's multiple meanings, interrogating the alignment between challenges and solutions through systems perspective, and reflecting on the different disciplinary approaches framing the debate of to the protein transition. Ultimately, this research seeks to influence how the protein transition is understood and approached, fostering a nuanced, reflexive, and systemic perspective as discussions continue to develop.

Interdisciplinary and systemic approach: A rich but fragile posture

This PhD adopts an interdisciplinary, systemic approach to the protein transition, incorporating perspectives from various disciplines, including bioengineering sciences, agricultural economics, political science, political economy, nutrition, and behavioural economics. Rather than focusing on a single dimension, such as consumer attitudes towards different protein-rich foods, environmental impacts, or political dynamics, this research explores the multifaceted nature of the protein transition, recognizing the complex interplay of factors that shape it.

This approach allows for a more integrative perspective, but it also poses challenges in terms of academic identity, as it transcends traditional disciplinary boundaries. The research reflects a

commitment to synthesizing diverse forms of knowledge and facilitating dialogue across disciplines. By doing so, it aims to contribute to a more comprehensive understanding of the protein transition and highlights the importance of interdisciplinary collaboration in addressing complex global challenges.

Research questions

The thesis engages with three main research questions, with corresponding envisioned contributions to scholarly and policy debates:

- 1) What are the meanings and functions of the protein transition in relation to food system sustainability?

(Shadow, Narrative, Discipline Papers)

Envisioned contribution: Defining and understanding the multiple meanings of an emerging concept, focusing on scientific literature.

- 2) How can the integration of diverse disciplinary perspectives be strengthened to contribute to a holistic and comprehensive vision of the protein transition?

(Discipline, Restatement, Reflection Papers)

Envisioned contribution: Interrogating how disciplinary traditions shape the study of the protein transition, influencing the questions that are asked, the types of evidence considered relevant, and the solutions deemed viable. By examining these dynamics, the thesis aims to highlight how disciplinary perspectives, each operating within its own epistemic rules and “truths”, can both illuminate and constrain the protein transition. The PhD also aims to demonstrate how structured interdisciplinary engagement, where researchers collaboratively negotiate assumptions and integrate insights can contribute to a more comprehensive vision of the protein transition.

- 3) What types of options and solutions are being proposed for the protein transition, and how well do they align with the underlying challenges the transition aims to address?

(Discipline and Paradox Papers)

Envisioned contribution: Demonstrating that the way the protein transition is conceptualized, whether within disciplinary silos or more holistically as part a system, shapes not only the types of solutions that are proposed but also their anticipated impacts. Crucially, it tests whether the causal-effect relationships remain coherent, effective, and aligned with the transition’s stated goals when assessed within the complexity of the food system.

The thesis includes five papers which are further described below (Figure 3).

The **Narrative Paper** (Paper 1) is a systematic review of peer-reviewed scientific literature published in English that explicitly uses the protein transition concept, where we began to unpack the meanings and functions of the protein transition in relation to food systems transition, directly informing the first research question.

The **Shadow Paper** (Paper 2) investigates how the concept of the protein transition intersects with concerns about livestock sustainability, building on findings from Paper 1 that highlighted a disconnect between consumer-focused solutions and the structural drivers of the protein transition. To investigate this, the paper revisits *Livestock's Long Shadow* (FAO, 2006), a seminal and widely cited report, to understand its influence on scientific discourse. Using bibliometric and text-mining methods, it maps the research landscape around the report, identifies key scholarly communities, and analyzes how they relate to protein transition communities. In doing so, it contributes to the first research question by offering insight into how the protein transition is being constructed, interpreted, and mobilized in relation to livestock sustainability.

Both the **Discipline Paper** (Paper 3) and the **Restatement Paper** (Paper 4) explore how collaboration across scientific disciplines can support a more holistic and systemic approach of the protein transition, addressing the second main research question. The **Discipline Paper** begins by examining how various academic disciplines engage with the protein transition as a concept. Drawing on expert interviews and literature analysis, it highlights the diversity of disciplinary perspectives, reveals boundaries between research communities, and analyzes how research questions are framed, along with the assumptions that shape them.

Going one step further, the **Restatement Paper** (Paper 4) represents a deliberate attempt to bridge disciplinary divides in the study of the protein transition. It responds to the challenge of synthesizing knowledge from diverse disciplines, including environmental science, nutrition, economics, and policy studies, into a single, coherent synthesis.

The **Paradox Paper** (Paper 5) critically examines key solutions and transition pathways proposed within the protein transition discourse, particularly those explored in the **Narrative Paper** (Paper 2). Through a perspective-driven approach grounded in an extensive literature review and expert interviews, this paper evaluates how well proposed solutions hold up when situated within the complexity of the food system. In doing so, the paper assesses both the alignment and potential misalignment between the challenges driving the protein transition and the impacts of the solutions being advanced, thus directly contributing to the third objective. It

further analyzes how different narratives shape and promote specific transition strategies, often reflecting underlying political and economic opportunities and agendas.

The **Reflection Chapters** (Chapter 4 & 5) reflect on the current transition pathways, the role of science and power dynamics in the protein transition. More specifically, Chapter 4 reveals how competing narratives, blurred boundaries between expertise and vested interests, fragmented disciplinary perspectives, and power dynamics at the interface of science, policy, and industry shape which approaches gain momentum. Chapter 5 explores how transformative change in food systems, particularly the protein transition, requires rethinking the role of science beyond producing evidence, emphasizing its active participation in shaping policy, societal norms, and institutional structures. It argues that sustainable transformation depends on understanding the interplay between structures, practices, and values, and on fostering a reflexive, interdisciplinary, and politically aware approach to scientific research.

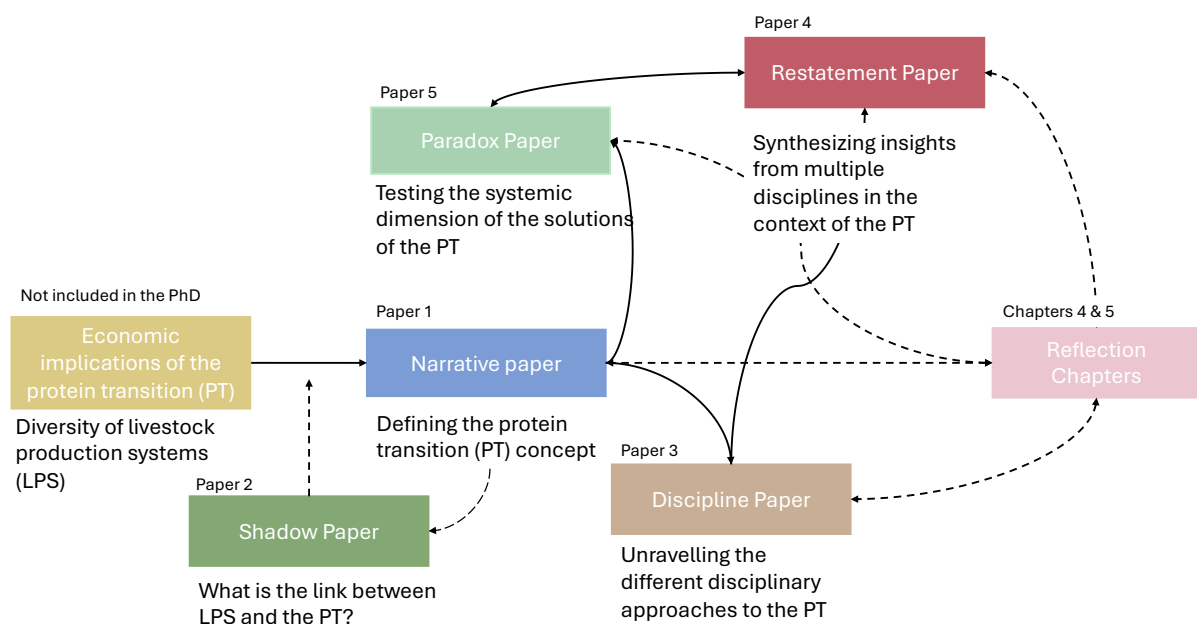


Figure 3: A comprehensive overview of the thesis papers and their interconnections.

The papers included in this PhD can be categorized according to their respective orientations toward scientific inquiry and policy relevance. While most of the work conducted throughout this PhD is grounded in academic research, particular attention has been paid to the potential

pathways through which scientific knowledge can inform, and be informed by, policy processes⁸. The research trajectory reflects an intentional evolution from internal scientific dialogue to broader engagement with societal and institutional actors.

Chronologically, the PhD began with the **Narrative Paper**, which focused exclusively on scientific literature. Similarly, the **Discipline Paper** remained within the academic realm, engaging with multiple disciplinary perspectives on protein transition. Both papers reflect an intra-scientific dialogue, essential to building a strong conceptual foundation but limited in their direct interface with policy processes.

The first tangible step toward bridging the science-policy gap was taken in the **Paradox Paper**. This paper extended beyond academia to analyze the narratives used by both public and private sector actors, including key European institutions. It incorporated empirical data from interviews with a broad set of stakeholders including scientists, but also policymakers from DG AGRI, representatives from consumer advocacy groups like BEUC, and advisory bodies such as the European Economic and Social Committee (EESC). This phase marked a deliberate move toward capturing the political and institutional dynamics that shape how scientific insights are received, contested, or used within policy arenas.

The **Restatement Paper**, aimed to strengthen the science-science interface by fostering greater conceptual clarity and alignment between scientific communities working on the protein transition. This effort was based on the premise that a more coherent and collectively articulated scientific position could serve as a more effective foundation for science-policy dialogue.

This trajectory of expanding engagement was also reflected in active participation in numerous events beyond academia. These included the EU Action Plan for Plant-based Foods Conference, organized by Members of the European Parliament—as well as events centered on the IEEP report *European Protein Diversification: Growing Opportunities for Farmers*. Further involvement included national-level workshops focused on developing plant-based value chains at regional and country scales. These activities underscored a commitment to engaging directly

⁸ Policy processes refer to the activities involved in developing, implementing, and evaluating policies, including agenda-setting, decision-making, and feedback, shaped by the interactions between various actors such as government officials, experts, interest groups, and the public.

with policy-relevant debates and actors, positioning the research within live political conversations about food system transformation.

Scope

What: The exploration of a single concept

In this PhD, we examine the protein transition both as a concept and as a transition pathway. While an in-depth exploration of what may appear to be a narrowly defined concept could seem ambitious for a single doctoral project, its significance extends well beyond the question of how we produce and consume “proteins”. The protein transition offers a particularly rich lens through which to analyze broader dynamics of sustainability transitions for several reasons.

First, it highlights the intrinsic link between normativity and transition. As a future-oriented concept, the protein transition is not neutral; it carries assumptions about what the world *should* look like and the paths we ought to take to get there. In the context of sustainability science, which is inherently problem-driven and action-oriented (W. C. Clark, 2007; Kates, 2011), the ways researchers define and narrate “options” play a central role in shaping transformative outcomes.

Second, the protein transition serves as a useful example for analyzing other food systems transitions. Its complex intersections with environmental, health, economic, and ethical concerns make it a valuable case for exploring how competing visions of sustainable food systems emerge, interact, and evolve. It offers transferable insights for examining transitions across broader food and agricultural domains.

Third, the protein transition represents a long-term strategic challenge. Given the escalating pressures of climate change, resource scarcity, and economic inequities, how societies manage the shift in protein production and consumption will profoundly influence the development of more sustainable and equitable food systems over the next decades.

Fourth, the protein transition acts as a kind of “Trojan horse” for debates that have long surrounded the impacts of meat production and consumption. Framing change in terms of “protein” creates a discursive shortcut: it enables conversations about meat consumption or alternatives without explicitly challenging the meat sector. While this framing can open space for dialogue and policy innovation, it also risks diluting the debate by downplaying the centrality of livestock in sustainability challenges.

At a time when the urgency of sustainability challenges often exceeds our capacity for timely action (Biermann & Kim, 2020; Springmann et al., 2018), the proliferation of “solutions” can be both empowering and paralyzing. By applying critical, reflexive analysis to the protein transition by questioning how options are framed, whose futures are imagined, and what normative assumptions underpin them, this PhD aims to contribute to the understanding and steering of sustainable transformations (Resare Sahlin, 2024).

Where: The geographical scope of the PhD

Out of the five papers included in the thesis, two are explicitly grounded in geographical specificity.

In the **Narrative Paper** (Paper 1), the scope is defined at the level of the OECD countries. This choice reflects the conceptual entry point of the thesis: the protein transition is not only relevant within the European Union but also across other high-income contexts where the core challenge is the overconsumption of animal-based proteins and their environmental, health, and ethical consequences (Parlasca & Qaim, 2022). By contrast, in many low- and middle-income countries, the issue lies in protein macro and micro-nutritional deficiencies, which are part of very different transition dynamics (Gatto et al., 2023). Thereby, limiting the analysis to OECD countries allowed the **Narrative Paper** to engage with the concept of protein transition responding to challenges linked to overconsumption and overproduction of meat, while avoiding conflation with contexts where issues at stake are fundamentally different.

In the **Restatement Paper** (Paper 4), the geographical focus is further narrowed to the EU for the following reasons. First, the protein transition has become a prominent topic across multiple levels of societal organization within the EU, including political initiatives, private sector strategies, and media discourse (European Commission, 2024; European Parliament, 2023). Second, the EU's unique governance structure, with both shared and exclusive competences in agriculture and food policy, along with an integrated market, enables coherent, union-wide approaches through instruments like the Common Agricultural Policy (CAP) and the Common Fisheries Policy (CFP) (Anania et al., 2015). Third, the EU ranks among the highest in per capita consumption of animal-based proteins, making it a particularly relevant context for debates on protein transition (Miller et al., 2022; Our World in Data, 2021a, 2021b; Parlasca & Qaim, 2022). Fourth, dietary shifts in the EU have significant environmental mitigation potential, given the carbon, land, and water footprints of current European diets (Adesete et al., 2023;

Aleksandrowicz et al., 2019; Mertens et al., 2021; Rancilio et al., 2022), alongside urgent ecological issues linked to the livestock sector such as nutrient pollution and biodiversity loss (De Pue & Buysse, 2020; Kok et al., 2006; Leip et al., 2015). Finally, the EU wields substantial global influence as the world's leading exporter of animal-based foods and a major importer of seafood—meaning that changes in its agricultural and dietary strategies carry international implications (EUMOFA, 2024; Guyomard et al., 2021; Swartz et al., 2010).

Protein sources considered

This thesis focuses primarily on terrestrial, farmed animals, specifically cattle, pigs, and poultry, as they play a central role in current food systems. However, in the **Restatement Paper** (Paper 4), we extend our scope to include aquatic animal proteins, encompassing both farmed (marine or freshwater aquaculture) and wild-caught (fisheries) sources, such as fish and aquatic invertebrates (e.g., shellfish, cephalopods).

We also include “alternative proteins”, though its definition evolved throughout the research, reflecting both ongoing debates in the literature and the challenges of terminology [**Restatement Paper** (Paper 4)].

In the **Narrative Paper** (Paper 1), we defined alternative proteins as insects, algae, plant-based single-cell proteins, and fungi, contrasting them with ‘traditional’ animal-derived proteins (meat, fish, dairy, and eggs). However, in the **Restatement Paper** (Paper 4), a further distinction was made between to distinguish plant and novel proteins:

- Plant proteins: Whole foods (legumes, cereals, nuts) and their products (tofu, tempeh, seitan), some of which have long-standing culinary traditions in Asia but remain less established in Europe.
- Novel proteins: Foods derived from plants, algae, fungi, terrestrial invertebrates, microbes, or animal cell cultures using technologies developed after 1950 (Rubio et al., 2020). This category includes terrestrial invertebrates (e.g., insects, earthworms, snails), cultured meat, plant-based dairy and meat alternatives, microbial proteins (e.g., mycoprotein), plant-based eggs, and grass protein.

By clarifying the objectives, scope, and interdisciplinary posture of the thesis, this chapter underscores the importance of reflexive, systemic, and policy-relevant approaches for understanding and guiding the protein transition. The research questions, papers, and analytical boundaries introduced here provide a structured foundation for the analysis that follows.

Building on this foundation, the subsequent chapters present the results of the thesis, critically examining the pathways, narratives, and proposed solutions that currently shape the protein transition.

Chapter 3: Results

This chapter presents the key findings of the thesis, drawing from the various published articles, while also incorporating additional insights developed throughout the research process. Each section revisits the methodology used in the respective papers, outlines the key results, discusses their contribution to the research questions and outlines the limitations of each paper. The final section outlines the limitations common to all the papers included in this PhD.

Scientific uses & interpretations of the protein transition concept

The concept of the ‘protein transition’ emerged in the scientific literature in the early 2000s as awareness grew about the environmental impacts of current protein consumption and production patterns, especially diets centered on animal proteins and intensive livestock production (Steinfeld et al., 2006; Willett et al., 2019). These environmental concerns were compounded by issues related to animal welfare, particularly in indoor, high-density systems where animals are often confined (Bartlett et al., 2023; Fraser, 2008), and by health concerns over the consumption of red (processed or not) and processed meats (G.-C. Chen et al., 2013; Nouri-Majd et al., 2022; Qian et al., 2020). One of the early works addressing this issue and using the term ‘protein transition’ was the 2006 book *Sustainable Protein Production and Consumption: Pigs or Peas?*, which explored the feasibility of replacing meat with plant-based alternatives (Aiking et al., 2006). The goal was to assess how replacing “pigs” by “peas” could improve the food system by reducing energy, land, and water use, while also mitigating the negative impacts on human health and animal welfare (Aiking et al., 2006). Since then, the term ‘protein transition’ has been repeatedly used across a wide range of scientific publications, spanning various journals and disciplines (Aiking & de Boer, 2020; Béné & Lundy, 2023; Jenkins et al., 2024). In engaging with the concept of the protein transition, we critically examined whether it is solely concerned with shifts in consumption patterns, such as replacing pork with plant-based alternatives, or whether it entails broader, systemic transformations encompassing production methods and the underlying political, economic, and social structures that shape contemporary food systems. In the **Narrative Paper** (Paper 1), we explore and unpack the diverse ways in which ‘protein transition’ has been interpreted and the different narratives as theories of change regarding how this transition should unfold.

The full version of this section has been published in Nature Food and is accessible using the following link: [Narrative Paper](#)

Box 2: Key terms of the Narrative Paper

Narratives:

Narratives provide structure and meaning to people's lives, shaping how we perceive the world by organizing experiences into recurring patterns. They serve as the primary means of conveying significance and play a crucial role in bridging the individual and society by connecting personal experiences with broader social, cultural or policy frameworks (Béné et al., 2019; Katz-Rosene et al., 2023).

In this paper, a **narrative** is defined by three key elements: a driver of change (the central issue to be addressed), a vision of a desirable future, and one or more pathways encompassing solutions for achieving that future. As such, narratives represent different perspectives on food system transformation—what the ideal future looks like and how to reach it.

Protein regime:

The term "**regime**" refers to the established and stable socio-technical system shaped by cultural norms, worldviews, and embedded structures such as physical infrastructure, laws, regulations, and policies (Geels, 2002, 2005, 2011). In this PhD, we define the protein regime as the dominant ways of producing and consuming proteins, shaped by these cultural norms, worldviews, and structural factors. This regime reflects the current practices and frameworks that govern how proteins are produced, distributed, and consumed, influencing both societal behaviors and policy decisions.

Following a Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) protocol⁹ and through searches on Scopus, we found 33 scientific publications that use ‘protein transition’ or ‘protein shift’ in their studies. More than two-thirds were published after 2019, showing a recent and growing interest in the concept. This paper's scope was limited to OECD countries, as they are typically high-income nations with relatively high levels of meat consumption (Parlasca & Qaim, 2022). Therefore, reducing animal-based consumption and production in these countries could yield significant environmental, health, and welfare benefits (Aiking, 2014).

Research explicitly using the ‘protein transition’ or ‘protein shift’ as a concept most generally defined it as a dietary shift away from animal-based products to include more alternative proteins. Yet, out of the 33 papers included in the systematic review, 13 did not define the protein transition. Production-side aspects were poorly mentioned even though the protein transition would, by design, affect both protein consumption and production systems (Rieger et al., 2023; Rööß et al., 2017). Moreover, this definition implicitly highlights consumers as key players in the transition as the protein transition focuses on shift in dietary patterns, while leaving the roles of other food systems stakeholders ambiguous or undefined.

Most papers tend to present and convey an idea of meat and animal-based products as the norm, defining other sources as ‘alternatives’ (e.g., Tziva et al., 2020), which can reinforce the dominant position of animal-based products in food systems (Voigt et al., 2024). Alternatives to animal-based proteins can encompass plant-based and novel proteins, whose definitions may vary across papers. For example, there is some variation in how the term “alternative proteins” is used. While plant-based proteins are sometimes included, the term often refers specifically to novel proteins produced using novel techniques developed after 1950 (Rubio et al., 2020).

The paper identified three main challenges providing rationale for the necessity of the protein transition, including i) reducing the environmental impacts of protein production and consumption systems, ii) preventing the ethical problem of animal welfare in indoor, high-

⁹ The PRISMA Protocol, formally known as PRISMA-P (Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols), is a standardized guideline aimed at enhancing the transparency and methodological rigor of systematic review protocols. It outlines key elements that should be included in a protocol, such as the review's objectives, eligibility criteria, search strategy, and methods for data extraction and bias assessment (Moher et al., 2015).

density livestock production systems, and iii) providing healthy diets for a growing population. Yet, among the reviewed paper, very few further elaborated on how the protein transition would effectively achieve the targets set. For example, it was not explicit how the protein transition would enhance animal welfare conditions, with some causal relationships left unspecified. In other words, it failed to explicitly explain why certain interventions would lead to certain outcomes, a concern that extends beyond the protein transition (see, e.g., Duru et al., 2022; Schreefel et al., 2025; Talenti, 2025). Moreover, there was limited attention given to assessing the effectiveness of different interventions, specifically, whether they have an impact and to what extent. For example, novel protein sources often face low consumer acceptance, which may limit their market share and reduce their potential impact within the broader protein transition.

The paper moreover identified three main narratives, which were defined as the combination of a driver of change (the main issue to be addressed), the objective regarding the desirable future, and one or more action pathways, encompassing a range of 'solutions' (*what* actions should be led). They were also linked to *who* is responsible for leading food systems transition (e.g., consumers or policymakers) (Table 1).

Table 1: The three main narratives identified include the driver of change, the main objective pursued and the action pathways

Narrative	Driver of change	Main objectives	Scale of intervention	Initiating actors	Action pathways
Consumer narrative	Unsustainable consumption patterns	Dietary shifts	Micro, defined as the consumer level	Consumers, civil society	• Reducing and substituting animal proteins • Changing to alternative diets
Techno-centered narrative	Inefficient protein production systems	Develop new, more resource efficient protein production systems	Meso, defined as the value chain level	Value chain actors, including commercial actors	• Research and development • Infrastructure and technology
Socio-technological transition narrative	Unsustainable food protein 'regime'	Agri-food system transition	Macro, defined as the regime level	Research, civil society, governments, commercial actors	• Redefining the food system regime • Redirecting public and private financial support • Implementing new regulatory frameworks

The most prominent narrative was the consumer-driven narrative which centers on unsustainable consumption patterns and advocates for dietary shifts (Aiking & de Boer, 2020; Dagevos, 2021; Dagevos & Verbeke, 2022) (Figure 4). In this narrative, consumers are seen as the key agents of change, with transformation occurring at the individual level (de Bakker & Dagevos, 2012). This aligns with movements like the 'less but better meat' initiative (Resare Sahlin et al., 2020), which positions consumers as active participants who exercise agency and wield influence through their food choices (e.g., 'vote with your fork') (Alarcon, 2015). This narrative assumes that consumers can influence production through their choices. It suggests that providing information and raising awareness about the problems associated with animal-based products will encourage consumers to reduce meat consumption and opt for alternatives (Aiking & de Boer, 2020; Hundscheid et al., 2022; Manners et al., 2020; Onwezen, 2022; Prag & Henriksen, 2020).

The second most prevalent narrative emphasized the development of alternative proteins. This narrative argues that consumers will modify their eating habits if alternatives are available and require minimal disruption to their current diets (Fernqvist et al., 2024) (Figure 4). In particular, this narrative highlights the efficiency of alternative protein production systems, which, for example, avoid feeding livestock with crops that could be consumed directly by humans or reduce greenhouse gas emissions per unit of production (Derler et al., 2021; Van Den Burg et al., 2021; Weindl et al., 2020; Weis, 2013). The goal is to produce protein with fewer inputs and reduced negative environmental impacts. Research and development efforts are encouraged to develop alternative options to animal-based foods (Lonkila & Kaljonen, 2021; Tuhumury, 2021; Tziva et al., 2020). In this narrative, change is driven by mesoscale actors, particularly producers and industry stakeholders, both small and large, who recognize economic opportunities in developing alternative products (Guthman et al., 2022). Additionally, research institutions and public-private partnerships contribute by advancing scientific knowledge, fostering technological innovation, and facilitating collaboration between industry, academia, and policymakers to accelerate the transition toward alternative protein sources (Tziva et al., 2021).

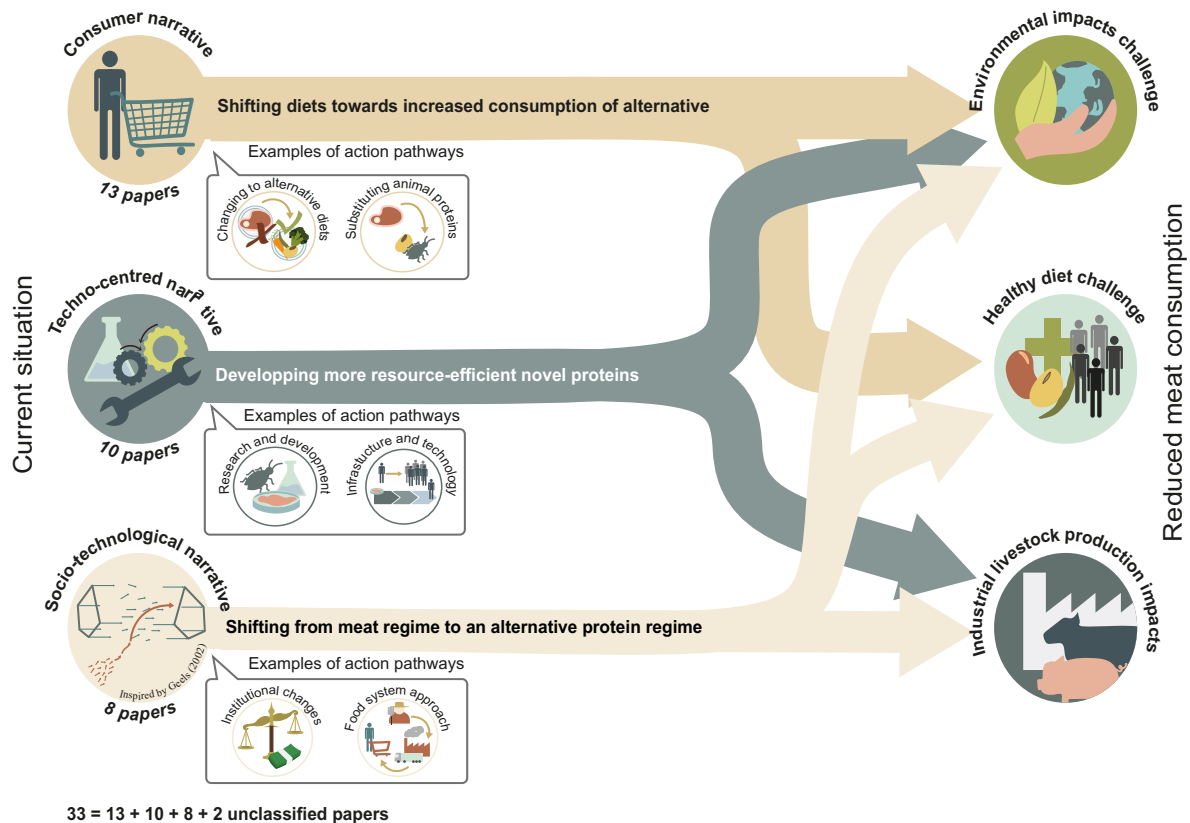


Figure 4: The three narratives of the protein transition. The left side depicts the present state and narratives of the protein transition, featuring examples of action pathways. The right side shows the primary challenges targeted by the protein transition. The lines represent the interactions between narratives and challenges.

The final narrative envisioned a reconfiguration of the entire “protein” regime, currently dominated by the animal protein sector (Box 2) (Figure 4). In this narrative, change requires engaging not only consumers but also influential food system actors such as lobby groups, retailers, and policymakers (Béné et al., 2019; Paloviita, 2021; van der Weele et al., 2019). It emphasizes that the transition should extend beyond dietary shifts to include reforms in livestock production, whether through the switch to more sustainable livestock production systems or a reduction in overall livestock numbers (Duluins et al., 2022; Prag & Henriksen, 2020). It also highlights the role of trust and systemic networks in driving transition dynamics, as change should come from a multi-actor perspective (Tziva et al., 2021). This vision calls for a reassessment of the political, institutional, and economic drivers that uphold the current regime, recognizing that lasting change will require structural shifts in power relations, policy priorities, and market incentives (Clapp et al., 2025; Guthman et al., 2022; Hundscheid et al., 2022).

The narratives identified in this paper, linked to different action pathways and solutions, were linked to policy instruments, shaping the direction of future food systems (Table 2). The study

underscores that the decisions policymakers make in the coming years, guided by these competing narratives, will determine not only what we eat and produce but also who is ultimately responsible and accountable for shaping food system transitions (e.g., consumers, commercial actors, or policymakers) (Anderson, 2024; de Bruin et al., 2025). Beyond competing in the discursive space, these narratives also influence financial flows, such as which types of research receive funding, or which production systems receive subsidies (Béné & Lundy, 2023; Feindt, 2018; Laufer & Jones, 2021).

Table 2: The main policy instruments across various narratives

Narrative	Main policy instruments associated with the narrative
Consumer narrative	• Taxes and subsidies to incentivize changes in consumption patterns • Labelling and certification to help consumers make informed choices • Education and awareness on the benefits of reducing animal protein consumption
Techno-centered narrative	• Research and development in alternative proteins • Funding and subsidies towards alternative proteins • Adapted regulatory frameworks for novel protein sources • Public-private partnerships
Socio-technological transition narrative	• Holistic policy framework overcoming political silos • Regional and national coordinated action plans involving multi-stakeholder collaboration (for example, governments, civil society organizations and private sector actors)

By framing what is perceived as the most pressing challenges in protein production and consumption, each narrative leads to distinct solutions and, in consequence, different ideas of prioritized policy instruments (Anderson, 2024). This paper contributes to a deeper understanding of the protein transition’s meanings and its role in food system sustainability. It highlights the plurality of perspectives and proposed solutions, while revealing a current predominance of narratives that emphasize consumer behavior change and technological innovation.

The protein transition, like other sustainability transitions, involves navigating a spectrum of possible futures, yet defining sustainable food systems remains inherently complex. Value judgments and diverse theoretical frameworks shape what individuals consider “good,” “bad,” or even “better” or “worse” (Bai et al., 2016; Place, 2024). In this sense, sustainability is best

understood as pluralistic, encompassing multiple and sometimes competing interpretations of “more sustainable” development (Béné et al., 2019; Blandon et al., 2025). These differing interpretations are expressed and contested through narratives, which frame not only what the protein transition is, but also what is ought to be.

The concept of “desirability” in sustainable food systems highlights how such narratives translate value judgements into visions of the future. They illuminate the trade-offs across social, economic, and environmental dimensions that must be navigated (L. Karlsson et al., 2025; Zurek et al., 2022). What constitutes a desirable, feasible, or just future is inherently normative (Resare Sahlin, 2024; Zurek et al., 2022). As sustainability science increasingly seeks to bridge knowledge and action, it must also confront the deeply political and value-laden nature of these transitions, raising fundamental questions about the relationship between science and politics (van der Hel, 2018).

The systematic review allowed us to confirm two hypotheses: 1) Various narratives within the scientific literature illustrate multiple options for achieving the protein transition; 2) Current solutions predominantly emphasize consumer behavior through dietary change and technological solutions through developing alternative proteins, while neglecting livestock production aspects and the structural and institutional factors shaping consumption behaviors and production patterns.

To our knowledge, this is the first paper to conduct a systematic review of the protein transition, a topic that has been emerging in scientific literature since the turn of the century. Through this paper, we investigate the meanings and functions of the protein transition in the context of food system sustainability.

The study's limitations include the potential for a broader search scope, as expanding to additional databases such as Google Scholar or Web of Science and incorporating grey literature could have provided deeper insights into how the concept is framed within academia, but also beyond, in political and civil society spheres. Additionally, limited attention was given to the role of actors and their (power) dynamics in shaping food system transitions. A science that aims to support societal transformations must engage with fundamental questions: What is changing, into what, how, and for whom? (Resare Sahlin, 2024; Zurek et al., 2022)

A scientometric retrospective of the Livestock Long Shadow Report

While multiple pathways of transition exist for achieving the protein transition, the **Narrative Paper** (Paper 1) reveals a dominant focus on consumer-focused strategies through dietary change and technological innovations such as alternative proteins. In contrast, the structural and environmental issues rooted in livestock production systems remain largely unaddressed as part of the solution. This observation leads us to a central hypothesis: a disconnect exists between the proposed solutions of the protein transition and the underlying drivers that initially prompted it, particularly those related to livestock production.

This led us to explore how the concept of the protein transition is connected to concerns about livestock sustainability. To do so, we revisited the FAO's 2006 report Livestock's Long Shadow for two key reasons. First, it emerged as one of the most frequently cited sources in the introduction sections of papers included in the **Narrative Paper**. Second, it is widely regarded as a seminal work that marked a turning point in how the environmental impacts of livestock production are framed. Its lasting influence is evident in its continued academic prominence, with over 3,000 citations recorded in Scopus as of 2024.

This paper pursues three main objectives: (1) to map and identify distinct research communities that have engaged with the Livestock's Long Shadow report; (2) to investigate the link between these communities and the protein transition communities identified in the **Narrative Paper** (Paper 1); and (3) to investigate whether issues of production and consumption are addressed separately within the scientific literature citing the report.

This section is the latest version of a paper currently under review. If you are interested in reading it, you can find the most recent version on my [ResearchGate](#) or [Google Scholar](#) profiles.

1. Introduction

The 2006 FAO report, “Livestock’s Long Shadow”, marked a pivotal moment in global awareness of the environmental consequences of livestock production. The report was published at a time when climate change was rising to the forefront of international policy, marked by milestones such as the enforcement of the Kyoto Protocol in 2005 (European Environment Agency, 2005). It offered one of the first comprehensive assessments of livestock’s multifaceted environmental impacts, notably estimating that the livestock sector was responsible for nearly 18% of global greenhouse gas emissions, a figure that surpassed emissions from the entire transport sector (Steinfeld et al., 2006). Beyond climate change, the report also linked livestock production systems to land degradation, deforestation, water and air pollution, overuse of natural resources, and biodiversity loss (Steinfeld et al., 2006). The report’s core message—that farmed animals are major contributors to anthropogenic greenhouse gas emissions—created a shockwave across scientific, political, and public arenas (Glatzle, 2014; Kristiansen et al., 2021). It was widely covered in global media and catalyzed responses from government agencies, environmental groups, and animal welfare organizations, many of which began calling for a reassessment of meat production and consumption practices on both environmental and ethical grounds (Brown, 2020; Vergunst & Savulescu, 2017; WWF International, 2022).

Despite strong pushback from livestock industry, and at times, scientific community, regarding its methodology and emissions estimates (Glatzle, 2014; Neslen, 2023; Pitesky et al., 2009), the report nonetheless catalyzed global discussions on plant-based diets and alternative proteins, notably influencing in particular the revision of dietary guidelines to address planetary health concerns (de Boer et al., 2014; Westhoek et al., 2014; Willett et al., 2019).

Since its publication, *Livestock’s Long Shadow* has become a widely influential and frequently cited work across numerous areas of research (Glatzle, 2014; Kingston-Smith et al., 2010; Scholten et al., 2013). Its enduring significance is reflected in over 3,000 citations on Scopus as of 2024.

2. Objectives and methods

This paper investigates how the FAO's 2006 report *Livestock's Long Shadow* (LLS) has shaped academic discussions on livestock and environmental sustainability. Specifically, it addresses three key objectives:

- 1) Map the research communities that have cited the report in scientific literature, to identify distinct clusters or intellectual groupings based on shared citation patterns and automated text analysis of articles abstract.
- 2) Investigate the link between communities related to the LLS and protein transition communities.
- 3) Assess whether issues of production and consumption are treated separately in the academic literature referencing LLS, or whether they are integrated in cross-cutting ways.

To meet these objectives, we apply two complementary analytical methods to a unified database. First, we use bibliographic coupling network analysis to examine how publications citing *LLS* are connected through shared references. This method enables the identification of research communities—groups of papers that rely on similar sources—thereby revealing the intellectual structure and dynamics of the field.

Second, we run a topic model on the abstracts of these publications to uncover dominant themes discussed within each research community. Topic modeling allows us to observe how topics are related to each other and group them by their proximity.

The methodology is further described by distinguishing three different phases:

- 1) Database creation
- 2) Quantitative analysis: Bibliographic coupling networks and topic modelling
- 3) Qualitative analysis: Community analysis

Each step of the methodology is synthesized in Figure 5.

2.1. Phase 1: Database creation

The database consists of two types of documents: Level-1 documents, which are documents citing *Livestock's Long Shadow*, and Level-2 documents, which are the references of Level-1 documents. Consequently, some Level-2 documents are also found to be Level-1.

Level-1 Collection and Cleaning

We first searched Scopus and Google Scholar¹⁰ (on August 5, 2024) using the keywords “*livestock’s long shadow*”, restricted to reference lists for Scopus. For each result, we extracted the abstract, keywords, and reference list using the `rscopus` package in R (Muschelli, 2019). This initial search returned 4,793 documents for Scopus and 7,130 for Google Scholar (see [Supplementary data Shadow](#), Appendix A for a more complete version).

We applied the following filters:

- Removed duplicates.
- Retained only records with a DOI.
- Included only articles, reviews, and book chapters (excluded books, preprints, editorials, etc.).
- Required that documents have a title, year, and journal information.
- For Level-1 documents: included only those with English abstracts, identified using the `fastText` package in R (Mouselimis, 2024).

After cleaning, 3,638 documents remained for Scopus, and 0 for Google Scholar. Using *Citation Chaser*, we retrieved missing abstracts, adding 61 more papers for Scopus, and 70 for Google Scholar for a total of 3,769 Level-1 documents (Table 3).

Level-2 References

We then extracted references from all Level-1 documents (Level-2). The same quality filters were applied. Scopus provided 136,449 Level-2 references, and Google Scholar and Citation Chaser further added 1,227 references, for a total of 137,676 Level-2 documents.

Final Dataset

The dataset comprises 141,455 records collected from Scopus and Google Scholar, consisting of 3,769 Level-1 and 137,676 Level-2 documents used to build the bibliographic coupling network (Table 3).

¹⁰ We also searched PubMed, CAB, Web of Science, and Google Scholar, but these added little value (under 150 documents pre-cleaning). Ultimately, 70 additional Level-1 papers were retained via Google Scholar and Citation Chaser.

Table 3: Level 1 & 2 references included from Scopus and Google Scholar by applying a set of including/excluding criteria

	Scopus			Google Scholar		
	Level 1		Level 2	Level 1		Level 2
	Raw	CC(1)	Raw	Raw	CC(12)	CC(2)
Initial entries	4 793	144	465 522	7 130	1 472	56 003
Final entries (unique papers)	3 638	61	136 449	0	70	1 227
Final entries (level1 contribution)	96.5%	1.6%		0%	1.9%	3 769
Final entries (level2 contribution)			99.1%			0.9% 137 676
Final entries (total contribution)	2,57%	0,04%	96,47%	0	0,049%	0,87% 141 445

2.2. Phase 2: Building the bibliographic coupling networks and running topic modeling

Regarding the bibliographic coupling method, we construct a series of *temporal* networks, where nodes represent citing documents and edges are “weighted” links between these nodes, based on the references they share (Goutsmedt & Truc, 2023). The process involved four key steps described below and synthetized in Figure 5.

Step 1: Temporal networks construction

Scientific literature often prioritizes recent contributions, which influences how bibliographic networks form over time. As a result, a bibliographic coupling network covering two decades is likely to show temporal clustering: documents tend to group together based on their publication period—newer papers clustering around shared recent references, and older ones around earlier citations. To mitigate this temporal bias in academic publication networks, we construct “temporal networks” using a moving five-year window (2007-2011, 2008-2012, ..., 2020-2024). To verify the robustness of our results, we have produced the results for different sizes of the moving window (see [Supplementary data Shadow](#), Appendix B). Once nodes are filtered by publication year, edges between nodes are established based on shared references. The construction of edges follows three criteria.

- **Minimum common reference threshold:** Two nodes are linked only if they share at least two references (edge threshold > 1). This prevents the inclusion of weak connections based on a single shared reference, thereby reducing noise in the network. We also constructed networks without applying the edge threshold parameter, for comparison (See [Supplementary data Shadow](#), Appendix B).
- **Bibliography length:** The length of a document's bibliography affects the likelihood of shared references. Longer bibliographies naturally increase the probability of common citations. Therefore, a shared reference is considered more significant when it appears in documents with shorter bibliographies. For example, if two articles with short bibliographies share two references, the weight of the edge connecting them will be greater than that of an edge connecting two articles with the same number of shared references but longer bibliographies (see [Supplementary data Shadow](#), Appendix C).
- **Overall citations of shared references:** If a reference shared by two articles is highly cited across the whole corpus, it is considered less significant than a rarely cited reference, which is more likely to indicate a meaningful connection between the articles. When two articles share two references, the less frequently cited reference contributes more to the edge weight between the two articles (see [Supplementary data Shadow](#), Appendix C).

To account for both the length of an article's bibliography, and the overall citation frequency of shared references, we use the "coupling similarity" measure (Shen et al., 2019). For comparison, we also examined the results using a simpler measure that considers only bibliography length when constructing edges (see [Supplementary data Shadow](#), Appendix B and C).

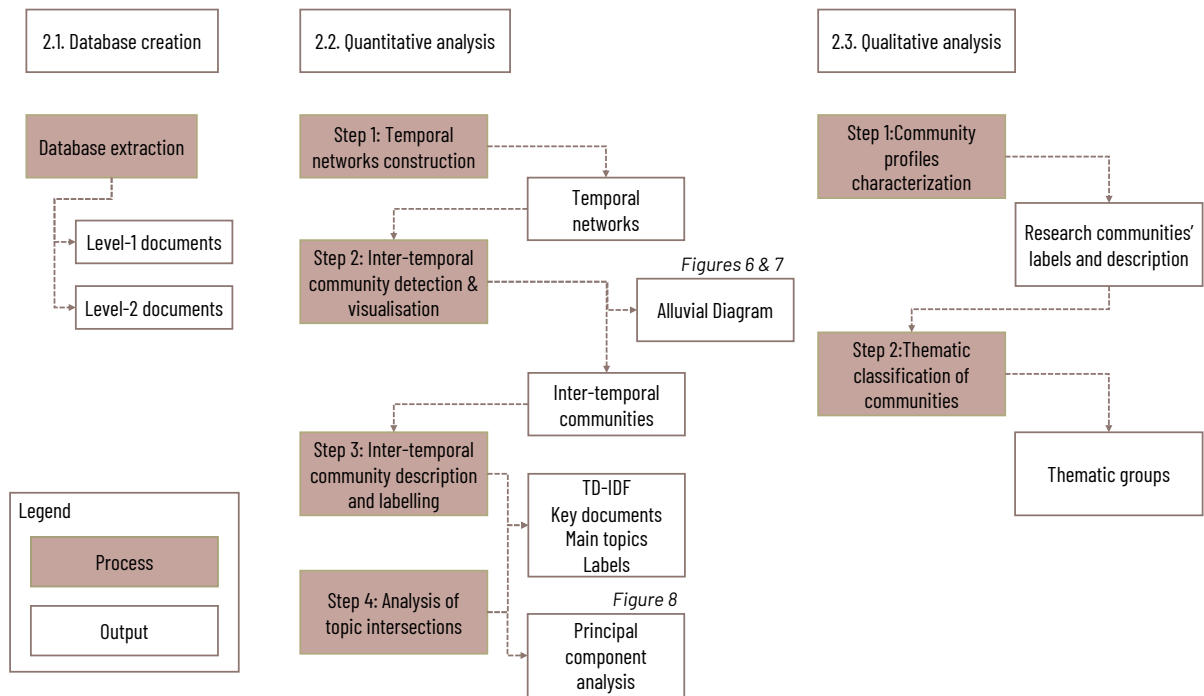


Figure 5: Methodological steps

Step 2: Inter-temporal community detection & visualization

Once the temporal networks were constructed, we used a community detection algorithm to identify distinct clusters of thematically or intellectually connected articles. For each temporal network, we applied the Leiden algorithm (Traag et al., 2019) which aims to find the best partition of the network to obtain dense connections among nodes within the same community, but sparse connections between nodes in distinct communities. By grouping nodes densely connected, such partition of the network allows to identify communities of articles talking about similar themes, using similar methods, data, or theory, etc.

In a second step, we seek to assess the persistence of certain communities across temporal networks. To do so, we compare all communities in pairs between two consecutive temporal networks. Two communities are considered the same “inter-temporal” community if they share more than 55% of their nodes in both directions—that is, if over 55% of the nodes in community i at time t are also in community j at time $t+1$, and vice versa.

Alluvial Diagram

Finally, we use an alluvial diagram to visualize the evolution of inter-temporal communities over time (Figures 6 and 7). Each vertical bar represents a temporal network and is divided into

segments corresponding to the inter-temporal communities that compose it, with segment size reflecting the number of nodes.

The flows between vertical bars depict the trajectories of communities across time. Specifically, they show the proportion of nodes from a community i at time t that transition into various communities at time $t+1$. In this way, the alluvial diagram reveals both the structure of each temporal network and how this structure evolved across successive periods.

Step 3: Inter-temporal community description and labeling

Once the inter-temporal communities have been identified, the next step is to generate a series of complementary indicators to characterize their thematic content (see [Supplementary data Shadow](#), Appendix D). These include: i) Term Frequency-Inverse Document Frequency, which highlights terms that are common within a given community but rare across others; ii) Citation-based metrics, used to identify key documents, influential nodes, and patterns of connectivity; iii) Topic prevalence, capturing the dominant themes associated with each community (see Step 4: Topic Modelling).

Together, these indicators provide an empirical basis for understanding the thematic contours of each inter-temporal community and support the assignment of preliminary labels. In the next phase of the analysis (Section 2.3), we draw on these metrics to guide a more in-depth qualitative interpretation and refinement of community labels.

Step 4: Topic modelling and analysis of topic proximity

Complementing the bibliometric analysis, this textual analysis helps clarify the substantive focus of different communities—such as climate mitigation, sustainable diets, or livestock systems. A topic model identifies k latent themes within a corpus—in this case, the abstracts of our Level-1 documents. The output of a topic model consists of two components:

- **Topics as mixtures of words:** Each topic is represented as a distribution over words from the corpus vocabulary, i.e., the set of unique terms in the corpus. For each topic, the model estimates the probability that a given word belongs to that topic.
- **Documents as mixtures of topics:** Each document is represented as a mixture of topics. For each document, the model estimates the probability that a given topic is present – this is referred to as topic *prevalence*.

We implement topic modelling using the *stm* R package (Roberts et al., 2013). Topic modeling serves two main purposes in this study. First, it provides additional information about the inter-temporal bibliographic communities identified earlier (see Step 3). For each inter-temporal community, we can assess which topics are most prevalent, enriching our understanding of their thematic content. In this way, topic modeling complements the bibliographic coupling analysis by focusing on semantic content rather than citation patterns. When both approaches converge on similar themes, such as livestock emissions and related terms like “methane” or “feed efficiency,” it strengthens the reliability of our interpretation (see [Supplementary data Shadow](#), Appendix E for more information on topic modeling implementation).

Second, topic modelling allows us to address the third research objective—evaluating whether production and consumption issues are treated as separate domains within the academic literature referencing LLS. To do so, we explore the similarity between topics. If documents are a mixture of topics, then topics can likewise be represented as mixtures of documents. Each topic is thus represented as a vector of length equal to the corpus size, with each value indicating the prevalence of the topic in a given document. We assume that if two topics are prevalent in the same documents, they are likely to share intellectual similarities.

We then performed a principal component analysis (PCA) to reduce the dimensionality of these topic vectors. PCA summarizes the variance across all topics into a smaller number of orthogonal components, allowing us to visualize and interpret topic similarity in a reduced-dimensional space (see [Supplementary data Shadow](#), Appendix H). We applied the k-means clustering algorithm to the full set of PCA components to identify groups of topics that are thematically related. Finally, we projected these clusters onto a two-dimensional space defined by the first two principal components (Figure 8). This projection enables us to examine which topics are grouped together and how they are positioned relative to one another along the two principal axes. These axes can be interpreted as latent dimensions that capture the most significant differences among the topics, thereby offering insight into the underlying structure of thematic variation—such as whether production- and consumption-related topics are conceptually separated.

2.3. Phase 3: Qualitative analysis of the results

Step 1: Community profiles characterization

A qualitative analysis was conducted for each community depicted in the alluvial diagram. This analysis focused on the origins of the community, key structural nodes (i.e., those with strong internal cohesion and limited external links), and main thematic trends identified through topic modeling. This approach clarified community formation and thematic focus, enabling the manual assignment of labels using both automated topic modelling and abstract content. The resulting labels and descriptions for each community are compiled in [Supplementary data Shadow](#), Appendix F.

Step 2: Thematic grouping

To address this paper's core objectives—namely, exploring the connections between communities referencing *Livestock's Long Shadow* (LLS) and those focused on the protein transition, a targeted classification process was undertaken allowing to assign communities to larger thematic groups.

The first step involved identifying which communities were associated with the protein transition. To this end, we adopted the framework proposed by Duluins & Baret (2024) which outlines three core narratives, each representing a distinct protein transition thematic group: the consumer-oriented group, focused on consumer behavior and dietary shifts aimed at reducing animal protein consumption and increasing alternative proteins in diets; the techno-centered group focused on innovation and technology-driven development of novel protein sources to replace or supplement animal proteins; and the socio-technological group envisioning systemic transformation of the entire food and protein regime.

Communities that did not align with this framework were classified using an inductive approach. These were grouped based on recurring topics and thematic patterns observed in the dataset, allowing us to capture shared areas of focus and organize the communities into coherent thematic categories.

This classification was conducted manually through a close reading of the labels and descriptions found in [Supplementary data Shadow](#), Appendix F, which served as the principal reference for assigning each community to the most appropriate thematic group (see [Supplementary data Shadow](#), Appendix G).

3. Results

The results are structured around two main axes: first, an alluvial diagram illustrating the evolution of different research communities over time (Figure 6), with a focus on protein transition communities (Figure 7); and second, a principal component analysis that classifies the recurring themes found in the papers included in the study (Figure 8).

3.1. Mapping the evolution of research communities over time

An alluvial diagram illustrates the temporal evolution of research communities over successive five-year windows, based on bibliographic coupling analysis (Figure 6). Each vertical bar represents the research network structure at a given time, with individual communities (or clusters) depicted as blocks proportional to their number of nodes (i.e., publications). The connecting flows indicate the movement of nodes between communities, capturing how communities emerged, persisted, merged, or dissolved over time. Communities sharing a significant proportion of nodes across time windows are defined as part of the same inter-temporal community (see Step 2 of section 2.2). Each community is numbered based on its order of appearance and labeled according to the themes identified in Section 2.3.

In total, 80 inter-temporal communities were identified, each with distinct thematic and temporal patterns. However, we focus on a subset of 29, selecting those that comprised more than 5% of the total network in at least one time window. This subsample represents more than 95% of all the nodes in the networks. Following the thematic grouping described in Section 2.3. (Step 2), these 29 communities were organized into seven thematic groups (indicated with colors in Figure 6), each representing a major research trajectory:

1. Emissions modeling and nutrient pollution communities
2. GHG emissions and climate change mitigation communities
3. Sustainable consumption practices related communities
4. Land use, biodiversity and ecosystem services communities
5. Livestock nutrition, microbiome and emission reduction strategies communities
6. Socio-technological related communities
7. Emergence of novel protein and food innovation communities

For each thematic group, the following paragraphs trace the chronological and thematic evolution of the associated research communities, emphasizing key developments and shifts over time.

We present the thematic groups starting by reading Figure 6 from left to right, thus presenting the thematic groups as they appear in time.

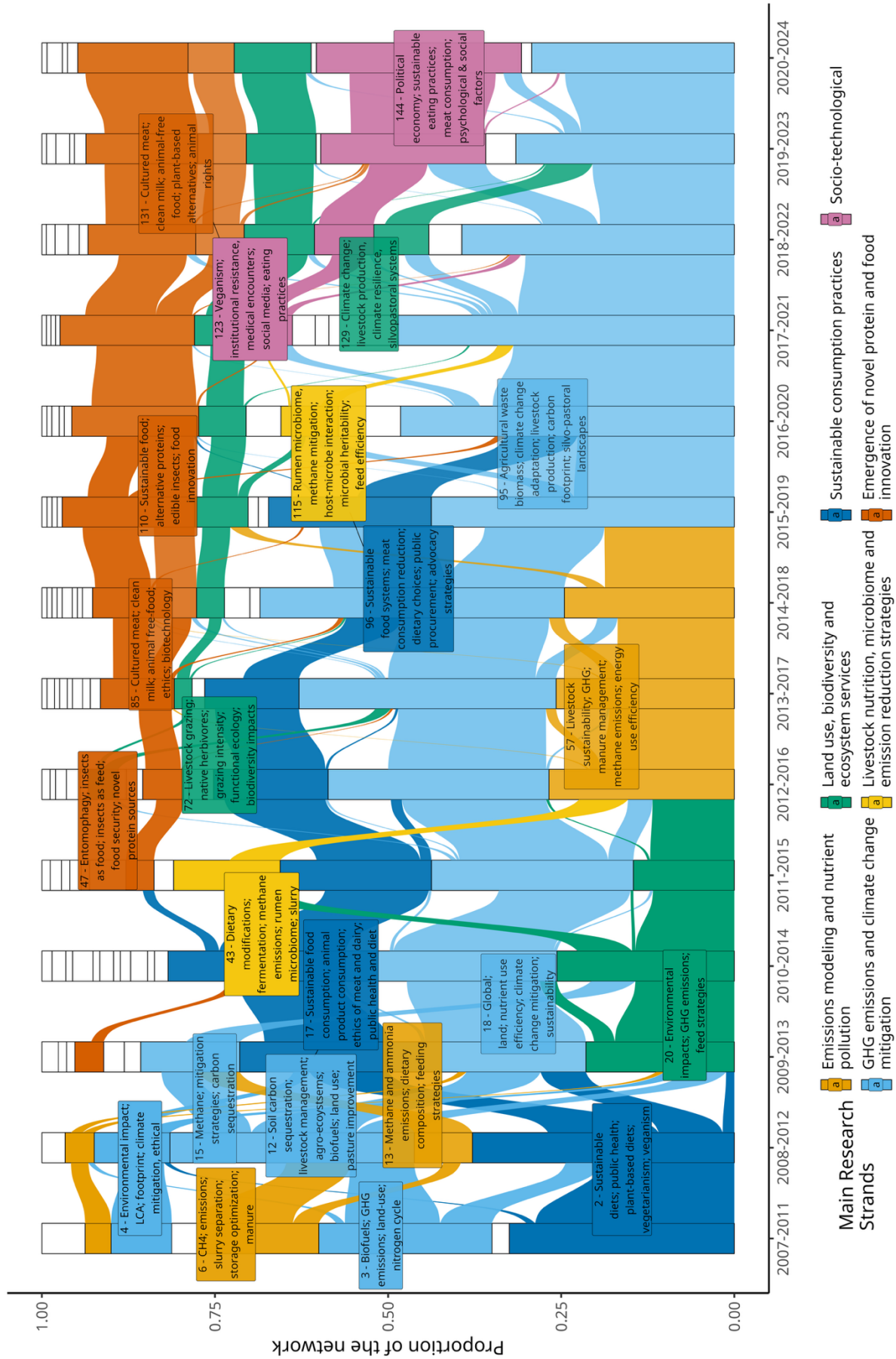


Figure 6: Alluvial diagram depicting bibliographic coupling communities identified using the coupling similarity method (Threshold = 2, Window = 5, Resolution = 0.6). The diagram illustrates the evolution and thematic shifts in literature citing Livestock's Long Shadow, with labels positioned at the points where communities emerge over time.

1. Emissions modeling and nutrient pollution communities

Between 2007 and 2018, research communities made important advances in understanding and mitigating emissions and nutrient pollution from livestock systems. Early efforts concentrated on spatial modeling of pollutant flows, particularly nitrogen compounds such as ammonia and nitrous oxide, as well as methane. These studies examined the geographic distribution and environmental impact of emissions, linking them to broader issues of climate change, air quality, and eutrophication (cluster 5). In parallel, technical research focused on methane mitigation through improved manure management practices, including slurry separation, composting, and optimized storage techniques (cluster 6).

Beginning around 2011, attention expanded to include the microbial and nutritional drivers of methane production. Research explored how dietary interventions, microbial inoculants, and feed composition influence rumen fermentation and the chemical properties of slurry, highlighting interactions between livestock nutrition, microbial activity, and manure emissions (cluster 43).

From 2012 onward, an integrated approach to livestock sustainability emerged, combining emissions reduction with energy efficiency and waste management. Studies assessed the environmental performance of different housing and production systems, e.g., organic, aiming to develop more efficient and climate-resilient models of livestock husbandry (cluster 57).

2. GHG emissions and climate change mitigation communities

Between 2007 and 2024, research on greenhouse gas emissions and climate change mitigation in agriculture has moved from global assessments to applied, region-specific strategies. Initial work between 2007 and 2011 critically examined the environmental impacts of livestock systems through life cycle assessments, specifically looking at the GHG footprint of livestock production systems, and the role of land use in CO₂ emissions. In parallel, studies explored the trade-offs between expanding biofuel production, livestock management, land-use change, and disruptions to the nitrogen cycle—emphasizing the interconnectedness of global food, energy, and environmental systems (cluster 4 & cluster 3).

Between 2008 and 2013, research shifted to focus on practical mitigation approaches, focusing on soil carbon sequestration, pasture management and restoration, and methane reduction via dietary interventions and improved manure management. These efforts aimed to develop

farming systems that support both productivity and environmental sustainability (cluster 12 & cluster 15).

From 2009 to 2018, a broader sustainability perspective took shape, linking nutrient use efficiency and land-use governance with global climate mitigation strategies. This phase emphasized the integration of ecological science, policy modeling, and economic instruments to advance resilient, efficient agri-food systems (cluster 18).

In parallel, since 2014, a more applied and regionally grounded body of research has focused on climate adaptation in livestock systems. This includes the use of agricultural waste biomass for renewable energy, the adoption of silvopastoral practices in the Amazon, and biodiversity-focused approaches to livestock sustainability (cluster 95).

3. Sustainable consumption practices related communities

Research on food consumption has played a central role in the debate on transforming food systems, developing through distinct intellectual currents that reflect evolving concerns about health, ethics, sustainability, and public policy.

The first research community emerged between 2007 and 2012, focusing on plant-based diets, public health, and climate change. This line of inquiry explored how reducing the consumption of animal products benefits both human and planetary health. It also highlighted the ethical motivations underpinning vegetarianism and veganism and examined the role of medical professionals in promoting dietary transitions (cluster 2).

By 2009, this community evolved to encompass a stronger ethical and political dimension, emphasizing individual moral responsibility and intergenerational justice. Researchers increasingly examined how policy instruments such as food labeling and consumption restrictions could guide sustainable dietary choices (cluster 17).

From 2015 onwards, the focus shifted to more institutional and systemic approaches. One key research community looked at public procurement practices and the role of advocacy in reshaping food environments. Scholars explored how institutional food services could serve as levers to reduce meat consumption, often mobilizing environmental arguments to support dietary change (cluster 96).

4. Land use, biodiversity and ecosystem services communities

Research on land use and ecosystem services has progressively shifted from ecological mechanisms to more integrated approaches addressing sustainability and climate adaptation. Early work focused on agro-ecosystems and pasture management in relation to soil carbon sequestration and greenhouse gas mitigation (cluster 12).

Around 2012, the focus shifted to the ecological roles of large herbivores and carnivores, exploring their impact on carbon cycling and ecosystem stability (cluster 60). This trajectory deepened with studies on the functional and biodiversity effects of grazing by native versus introduced herbivores, highlighting how grazing intensity shapes ecosystem responses in drylands and semi-arid environments (cluster 72).

From 2015 onward, research increasingly addressed the sustainability of livestock systems in tropical and forested regions, particularly through silvopastoral practices and landscape-level approaches to climate resilience (cluster 129 & cluster 95). These communities focused on improving livestock welfare and reducing environmental impact while strengthening food and nutritional security. In parallel, attention turned to the role of agricultural waste, carbon footprints, and sustainable intensification strategies in the Amazon and other vulnerable landscapes (cluster 95).

5. Livestock nutrition, microbiome and emission reduction strategies communities

Between 2008 and 2022, research communities made significant strides in developing integrated strategies to reduce greenhouse gas emissions from livestock by targeting nutrition and microbial processes. Early investigations focused on dietary interventions such as incorporating tannin-rich forages and adjusting crude protein levels to lower methane and ammonia emissions while enhancing feed efficiency and manure quality, meaning its nutrient content and suitability for use as fertilizer (cluster 13). Parallel studies explored the environmental benefits of utilizing feed byproducts to further reduce methane emissions and improve manure chemistry, referring to the chemical composition of manure (e.g., nitrogen forms, pH, and carbon content) in ways that lower its contribution to eutrophication and global warming potential (cluster 20).

Beginning in 2011, attention shifted towards the impact of feed additives, microbial inoculants, and dietary modifications on rumen fermentation and slurry emissions, underscoring the critical connections between nutrition, microbial activity, and environmental outcomes (cluster 43).

From 2016 onward, a genomic and microbiological perspective emerged, investigating the rumen microbiome, host-microbe interactions, and heritable microbial traits—highlighting how genetic and dietary factors jointly shape emissions and feed conversion efficiency (cluster 115).

6. Socio-technological related communities

Building on a broader shift in research focus, two distinct research communities have emerged since 2017, both reflecting a socio-technological perspective moving beyond individual behavior to explore systemic transformations involving evolving norms, regulatory frameworks, and coordinated action across the food system.

The first research community, developed between 2017 and 2022, explores how plant-based diets challenge entrenched social norms, particularly within institutional settings like healthcare. Here, veganism is often stigmatized and framed as a deviant or fringe practice. This research also examines the influence of media and digital activism—such as the Finnish Vegan Challenge and documentaries like *Cowspiracy*—in shaping public perceptions. Additionally, it addresses ongoing challenges around food labeling and the competition between alternative and animal-based protein foods (cluster 123).

The second research community, active from 2019 through 2024, focuses on the political economy of meat and the psychological and social factors that shape red meat consumption. It investigates how consumers navigate tensions between ethical or environmental concerns and everyday eating habits. Tools like the Swedish Meat Guide are examined for their role in enabling more informed choices, while attention is also given to how institutional norms may continue to reinforce barriers to change (cluster 144).

7. Novel protein and food innovation communities

Research into novel proteins emerged as a distinct field in 2009, when scholars began exploring the potential of insects as food and feed. These studies emphasized the nutritional and ecological benefits of entomophagy and discussed the socio-cultural and regulatory challenges of integrating insects into Western diets (cluster 19 & cluster 47).

From 2016 onward, this research evolved to encompass a broader vision of food innovation, including safety and nutritional assessments, consumer acceptance, and the ethical and marketing dimensions of alternative proteins. This evolution marked the rise of a more integrated perspective, where novel proteins are situated within a larger agenda of structural

transformation aimed at tackling global challenges such as food security, environmental sustainability, and public health (cluster 110).

Meanwhile, work on lab-grown and cultured alternatives gained prominence from 2014 onward. Researchers examined technologies such as cultured meat, clean milk, and advanced plant-based proteins, along with their implications for biotechnology, animal welfare, and market dynamics. These investigations also considered the political economy of cellular agriculture, and the cultural and ethical changes needed to reimagine food production (cluster 86 & cluster 131).

Evolving communities in the protein transition

The three thematic groups, including “Sustainable consumption practices” related communities, “Socio-technological” related communities and “Novel protein and food innovation” communities, reflect key research communities associated with the protein transition, evolving from broad concerns about sustainable consumption to more targeted investigations into alternative protein sources—first insects, then cultured meat—and gradually moving toward a systemic understanding of the socio-structural factors shaping dietary choices (Figure 7).

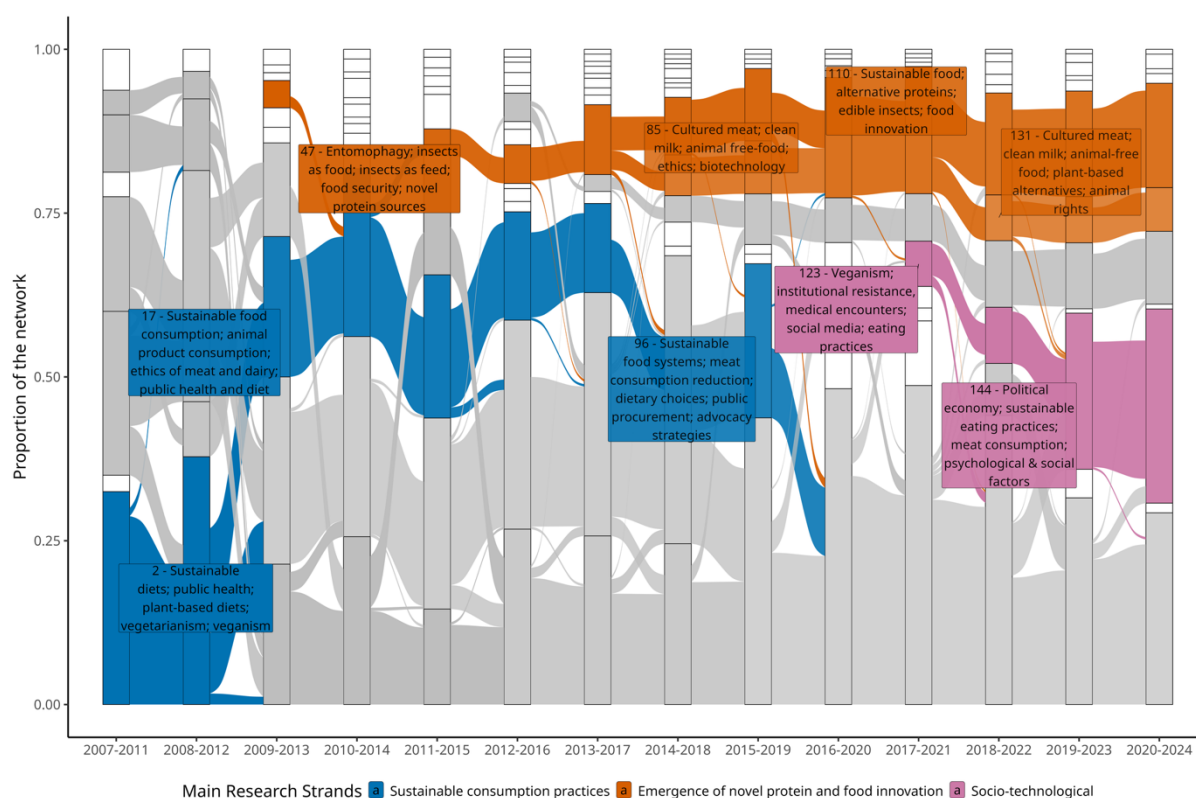


Figure 7: Alluvial diagram of bibliographic coupling communities with a focus on the protein transition related communities, namely: sustainable consumption practices, socio-technological, emergence of novel proteins and food innovations communities.

3.2. Principal Component Analysis

With the principal component analysis (PCA), four clusters were identified based on all principal components, but the Figure 8 displays only the first two principal components, which explain 10% and 7% of the variance, respectively. Although the explained variance is relatively low, indicating that much of the variation among topics is captured by higher-order components, these first two axes still capture meaningful distinctions in the overall structure of topic similarity.

The horizontal axis reveals a clear gradient. On the right side, topics cluster around consumption-oriented themes (e.g., Topic 9 and 36) and alternative proteins (e.g., Topic 28 and 39). On the left side, topics are more aligned with livestock production systems and their environmental impacts, including greenhouse gas emissions (Topic 7) and livestock waste management (Topic 19).

The vertical axis appears to capture a scale gradient from specific to systemic focus. Topics at the top deal with more targeted elements, such as diets (Topic 39), meat consumption (Topic 36), or animal welfare (Topic 23). In contrast, the lower part of the plot features broader, system-level themes, such as climate change assessments (Topics 7 and 12), global agricultural land use (Topic 35), and crop production systems (Topic 27).

While PCA helps reveal the underlying structure of topic similarity and allows us to visualize broad thematic gradients within the literature, it does not directly assess how these topic clusters correspond to the thematic groupings identified through bibliographic analysis. To explore this alignment more systematically, we analyzed the distribution of topic clusters identified through topic modeling in relation to our predefined bibliographic communities, examining whether specific themes were disproportionately represented within each group. This comparison provides insight on how the conceptual structure of the literature (as captured by topic modeling) mirrors its citation-based structure.

To quantify this relationship, we computed the log-ratio comparing the *observed* and *expected* co-occurrence of documents in each cluster-theme pair (see Supplementary data Shadow, Appendix I for more details). Positive log-ratios suggest that a topic cluster is more prominent in a bibliographic thematic group than would be expected by chance, while negative values point to under-representation. These relationships are visualized in a heatmap (Figure 9). The results reveal that Clusters 1 and 3 identified through the PCA are notably associated with thematic groupings related to the protein transition (that is thematic groupings: socio-technological,

sustainable consumption practices and the emergence of novel protein and food innovation). In contrast, Clusters 2 and 4 are more aligned with bibliographic communities focused on livestock production systems, with cluster 4 referring more to system-level topics such as global land use changes.

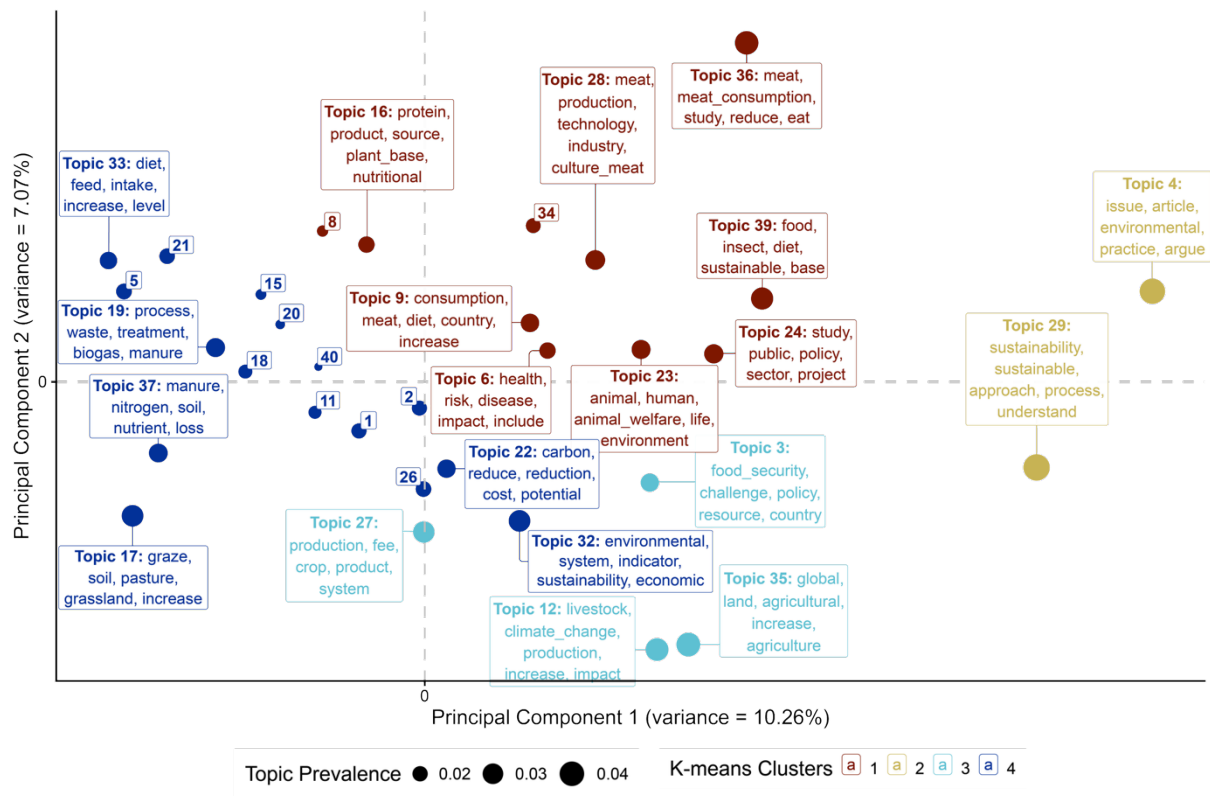


Figure 8: Topical landscape of the literature: PCA reveals gradient from consumption to production (left to right) and from specific to systemic focus (from bottom to top).

Taken together, this comparison reinforces the PCA findings: themes linked to the protein transition are concentrated in topic clusters emphasizing consumption-related dynamics, while other thematic communities are more aligned with system-level and production-oriented concerns.

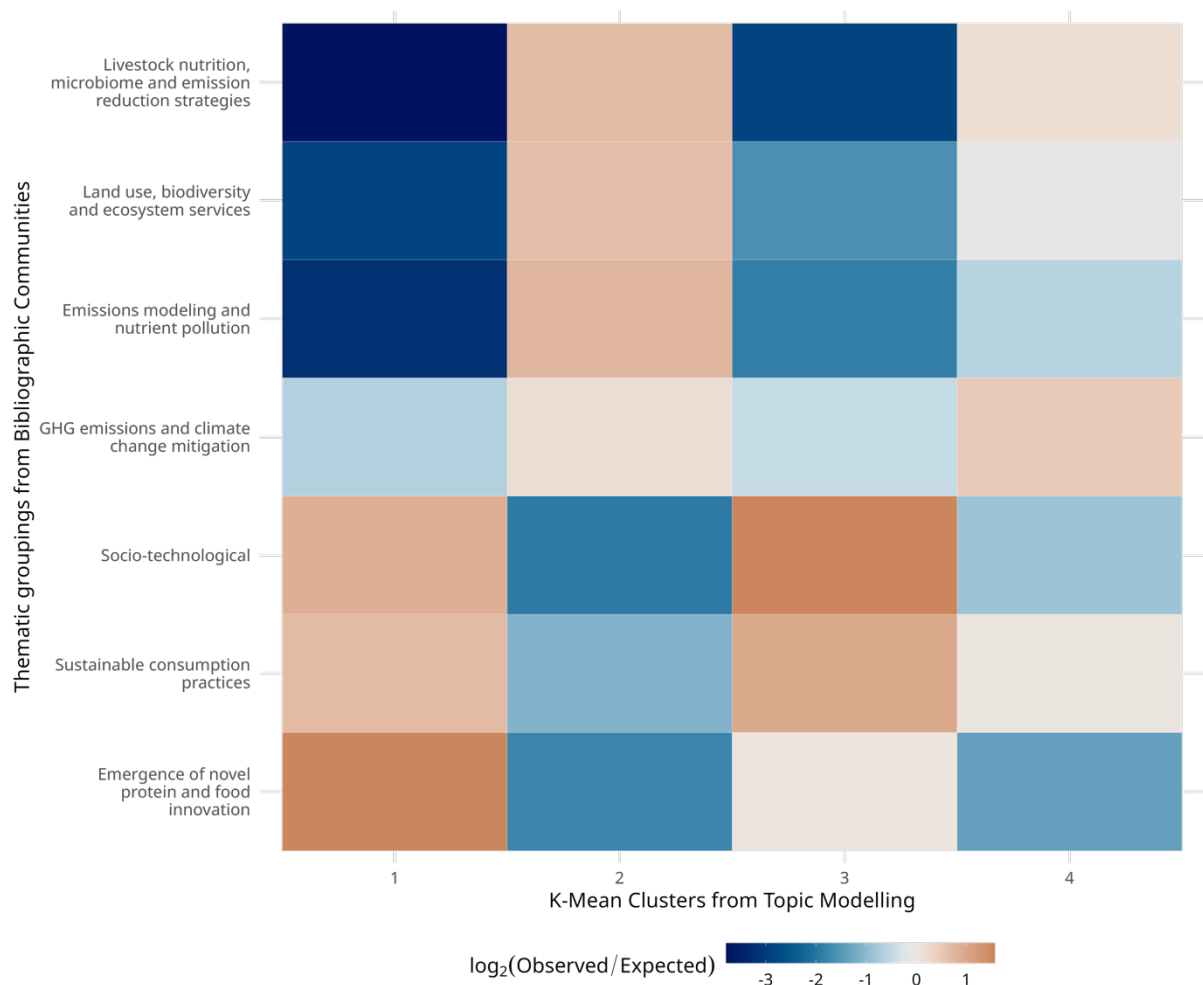


Figure 9: Log-ratio heatmap comparing topic clusters (K-Means) with bibliographic thematic groupings. Each cell shows the $\log_2$ -ratio between observed and expected co-occurrences of documents in a given topic cluster and thematic group. Positive values indicate over-representation (greater overlap than expected by chance), while negative values indicate under-representation.

4. Discussion

4.1. Key takeaways of the results in light of the research questions

Through the combined use of bibliographic coupling and topic modeling, we identified and characterized seven distinct thematic groups each containing different research communities that have cited the Livestock Long Shadow report in scientific literature. These groups represent clusters of research communities that are connected through shared citation practices and topical similarity. The research communities covered a broad spectrum of themes, ranging from emissions modelling and nutrient pollution to climate change mitigation, sustainable consumption, land use and biodiversity, and the emergence of novel proteins and food innovations. Notably, three of these thematic groups are strongly aligned with the three

narratives of protein transition identified in Duluins & Baret (2024), encompassing sustainable consumption, socio-technological dynamics, and protein-food innovations.

While some overlap exists, our findings suggest that the communities focusing on livestock systems and their impacts at large and those focused on the protein transition remain relatively siloed scientific communities. The protein transition research is more prominently associated with consumption-side questions and often incorporates perspectives from public health, ethics, and socio-technical systems. In contrast, livestock-related communities primarily address environmental impacts, emissions modeling, land use, and biodiversity issues.

Using principal component analysis (PCA), we further examined the thematic structure of topics discussed in the literature. On the horizontal axis, the analysis revealed a marked separation between production and consumption themes. Consumption-oriented topics, such as meat intake reduction, plant-based diets, and ethical eating, cluster distinctly from those related to production systems, like livestock emissions, manure management, and land use. This structural separation suggests that academic discourses and practices continue to treat these domains in parallel rather than in an integrated, systems-oriented fashion.

Moreover, a secondary axis PCA also distinguishes specific interventions (e.g., dietary change, consumer behavior, animal welfare) from broader systemic concerns (e.g., climate change, global land use, crop-livestock integration). This suggests that much of the literature is between micro-level behavioral studies and macro-level environmental modeling, with relatively few studies bridging both scales.

4.2. Limitations of this study

A first limitation concerns the data used for topic modeling. Specifically, we relied on abstracts, which—although they provide a concise summary of article content—are inherently limited in depth. As short texts, abstracts constrain the expressiveness and granularity of thematic analysis, potentially oversimplifying the content and obscuring less prominent themes. This may reduce the capacity of topic modelling to fully capture the richness and complexity of scholarly debates within the corpus.

A second limitation regards to the network clustering method used, namely, the Leiden algorithm, which suffers from the classic “resolution limit” problem associated with modularity-based algorithms (Traag et al., 2011). Such algorithms tend to overlook smaller communities when optimizing modularity, instead favoring larger communities that contribute more to the

overall modularity score. As a result, thematically coherent but relatively small groups of documents may be merged into broader communities, potentially obscuring finer-grained intellectual distinctions within literature. This is likely to happen in our case, notably with the largest communities (Cluster 18, for instance). To minimize the impact of this issue, we varied the resolution parameter of the Leiden algorithm, which controls the number of communities identified. We also tested alternative edge weighting measures and varied the size of the time window to construct temporal networks (see Supplementary data Shadow, Appendix C). These variations produced different community partitions within each temporal network, and consequently different inter-temporal communities. Our aim was to compare the results obtained under these alternative specifications with our chosen set of parameters, in order to ensure that the observed trends are robust and not artifacts of specific parameter choices.

5. Conclusion

This paper has examined how the *Livestock's Long Shadow* report shaped academic discourse on livestock and environmental sustainability. By mapping the research communities that cite the report and analyzing the thematic content of their work, we identified seven major thematic groupings of research communities, ranging from emissions modeling and land use to sustainable consumption and food innovation. Among these, three thematic groupings align closely with the field of protein transition, highlighting a growing interest in plant-based diets, socio-technical change, and alternative proteins.

Our findings point to a persistent fragmentation in the literature with research communities focusing on livestock production and their environmental impacts remaining largely distinct from protein transition communities focusing on consumption and alternative proteins. The principal component analysis confirms this divide, revealing a structural separation between production- and consumption-focused topics, with protein transition communities focusing on the latter, as well as between specific interventions and broader systemic concerns.

Disciplinary contributions to the protein transition

The **Narrative Paper** (Paper 1) revealed the existence of distinct narratives, each reflecting a different theory of change. While this paper was not designed to test disciplinary influences, we strongly sensed that these narratives were linked to different academic disciplines. For instance, the consumer-driven narrative appeared closely aligned with behavioral economy and psychology disciplines. This observation raised an important hypothesis: that academic shape how the protein transition is conceptualized, which in turn influences what kinds of interventions are considered viable or desirable.

The **Discipline Paper** (Paper 3) explores this hypothesis more directly by examining how different academic disciplines, namely Behavioral Economics, Political Economy, and Nutritional Sciences, formulate research questions, define problems, and envision solutions for the protein transition. The analysis shows that each discipline emphasizes different dimensions of the transition, leading to distinct framings of both challenges and possible interventions.

The paper specifically aimed at i) highlighting the diversity of disciplinary approaches to the protein transition and, thus, the disciplinary boundaries; ii) examining the framing of research questions and the assumptions they reflect, emphasizing differing perspectives on the nature of change and the pathways through which it occurs; and iii) investigating the risks and opportunities of siloed disciplinary approaches in the context of the protein transition.

This section summarizes the latest version of a paper that is currently under review. We hope it will be published soon, and recommend checking [ResearchGate](#) or [Google Scholar](#) for the most up-to-date information.

Box 3: Key terms of the Disciplinary Paper

Disciplinary approaches:

Disciplinary approaches refer to the methods, frameworks, and perspectives unique to a specific academic discipline used to study and address a particular problem or question. These are shaped by the discipline's ontology (how reality is understood) and epistemology (how knowledge is generated), which together influence the tools, concepts, and criteria deemed valid for analysis (Moon & Blackman, 2014).

Disciplinary Habitus:

The concept of **disciplinary habitus**, rooted in Bourdieu's theory of habitus, refers to the deeply embedded ways of thinking, valuing, and practicing that researchers develop through their education, professional training, and engagement within a specific academic field. It shapes how scholars perceive problems, formulate research questions, choose methodologies, and interpret findings (Bourdieu, 2004).

Because disciplinary habitus is acquired over time through immersion in a particular discipline, it creates a sense of belonging and coherence within academic communities. However, this can also lead to difficulties when navigating interdisciplinary spaces—not so much due to resistance, but because researchers may find it challenging to position themselves within institutional structures that are still largely organized around disciplinary boundaries (Salmela et al., 2025). This concept helps explain why certain academic traditions persist and why shifting perspectives within a discipline can be challenging (Bourdieu, 2004).

Cross-disciplinary approaches:

We refer to **cross-disciplinary approaches** as encompassing all efforts to transcend traditional disciplinary boundaries, including inter-, trans-, and multidisciplinary practices.

This study employed a two-step methodology, combining expert interviews with a literature review to analyze how different academic disciplines (Behavioral Economics, Nutritional Sciences, and Political Economy) frame the protein transition. These disciplines were selected based on their alignment with the three narratives identified in the **Narrative Paper** (Paper 1): the consumer-driven narrative, the techno-centered narrative, and the socio-technical narrative. The choice of these disciplines was necessarily selective and arbitrary, as other disciplines could also have been chosen for their alignment to the narratives of Paper 1 (e.g., psychology rather than behavioral economics for the consumer-driven narrative). Experts from each discipline participated in semi-structured interviews, which explored disciplinary perspectives, problem framing, and key methodological approaches. The disciplines “definitions” were introduced at the start of the interviews as a heuristic device to prompt reflection¹¹: experts were asked whether they identified with the discipline mentioned, and if so, how, and if not, why not. These exchanges, while not the central focus of this paper, often led to rich discussions about disciplinary boundaries and crossovers. The interviews were complemented with literature data. Two primary sources were used for selecting the papers: (1) expert recommended papers within their own expertise; and (2) a targeted search on Scopus, with detailed research strings. Using a saturation principle, we analyzed a final set of 24 papers (nine papers from political economy and consumer behavior, and six from nutritional sciences) using a standardized coding framework¹². This framework was developed through a combination of inductive and deductive approaches, as this combination allowed categories to emerge directly from the data, while building on existing theoretical concepts and prior literature. The study then conducted a cross-disciplinary analysis to compare how each field conceptualizes key themes such as consumer behavior, price, protein definition, and feed-food

¹¹ **Behavioral Economics/Consumer Behavior:** Studies how psychological, cognitive, emotional, cultural, and social factors influence individual decision-making, with a particular focus here on consumer choices related to protein sources.

Nutritional Sciences: Investigates how nutrients and bioactive components of food affect human health, growth, reproduction, and disease, while also considering broader dietary patterns, nutritional status, and public health approaches to diet.

Political Economy: Examines the interaction between political institutions, governance, and economic systems, with attention to how policies, power relations, and market dynamics shape the protein sector.

¹² Examples of codes include style of reasoning, main problem definition, proposed solutions or implicit assumptions.

competition, highlighting both divergences and areas of complementarity in the disciplinary framing of key concepts of the protein transition.

This study reveals how different academic disciplines frame the protein transition, shaping their research focus, methodologies, and assumptions. Behavioral Economics centers on consumer decision-making, exploring psychological and social drivers behind adopting alternative proteins, while Nutritional Sciences focuses on protein quality, digestibility, and health impacts of various protein sources. Political Economy, in contrast, examines the socio-economic and political forces influencing the protein sector, emphasizing power dynamics, corporate influence, and the framing of food system challenges.

Methodologically, Behavioral Economics employs mixed-method approaches, combining quantitative surveys and experiments with qualitative methodologies such as interviews. Nutritional Sciences relies on experimental data, particularly randomized controlled trials and biochemical assessments of protein quality. Political Economy takes a qualitative, theoretical approach, utilizing methods such as discourse analysis, case studies, and interviews to investigate policy and market dynamics. Reasoning styles also differ: Behavioral Economics and Nutritional Sciences primarily use inductive reasoning¹³ to draw conclusions from empirical data, while Political Economy mainly relies on abductive reasoning¹⁴.

As the protein transition unfolds within a complex system, each discipline focuses on different subsystems, emphasizing some elements of the system while downplaying others. For instance, Nutritional Sciences tend to focus primarily on the nutritional content of various protein sources, often overlooking the political, social, and economic factors that shape consumer choices. Additionally, the relative importance of specific elements within the system varies by discipline—for example, consumer behavior is a central focus in Behavioral Economics, yet it holds a more peripheral role in Nutritional Sciences. Moreover, common elements of their sub-systems such as price or consumers are perceived differently across disciplines. Behavioral Economics views price as a key factor influencing consumer adoption, whereas Political Economy sees it as a reflection of power structures and market dynamics (Table 4). As for consumers, Behavioral

¹³ Inductive reasoning, or induction, is making an inference based on an observation, and often an observation of a sample. You can induce that the soup is tasty if you observe all of your friends happily consuming it (Merriam-Webster Dictionary, 2025).

¹⁴ Abductive reasoning, or abduction, is making a probable conclusion from what you know. If you see an abandoned bowl of hot soup on the table, you can use abduction to conclude the owner of the soup is likely returning soon (Merriam-Webster Dictionary, 2025).

Economics identifies diverse consumer segments based on taste, health, sustainability, and sociocultural preferences, focusing on psychological barriers and interventions to shift behavior (Table 4). Nutritional Sciences highlights health-conscious yet often uninformed consumers, emphasizing the potential of education and labeling in changing consumer behaviors. Political Economy sees consumers as both targets of corporate and socio-political influences and agents who respond to, influence, or resist them. Definitions of protein also vary across disciplines, with Behavioral Economics categorizing proteins by source with which consumers engage in commercial settings (e.g., plant-based vs animal-based), Nutritional Sciences assesses its bioavailability and health value—as if these alone determine uptake—while Political Economy views protein as a commodity shaped by corporate interests in a system where consumer agency is often constrained (Clapp et al., 2025) (Table 4).

Table 4: Disciplinary perspectives of common elements considered in the protein transition

Theme	Behavioral Economics	Nutritional Studies	Political Economy
Price	Price acts as both barrier and incentive in consumer decisions.	Price is mentioned within consumer behavior but is not a central research focus.	Price is a tool and symbol of power, reflecting market strategies and socio-economic influences in protein markets.
Consumers and Drivers of Consumption	Highlights diverse consumer segments influenced by taste, health, sustainability, and sociocultural norms; studies psychological barriers and interventions.	Emphasizes health-conscious but often poorly informed consumers; advocates education, labeling, and guidance.	Views consumers as both targets of marketing and agents influenced by socio-political structures and corporate narratives.
Protein Definition	Defines proteins by origin (animal, plant, fermented); focuses on consumer perception and substitution potential.	Defines proteins by nutritional quality, digestibility, and bioavailability; discusses nutritional adequacy and processing effects.	Views proteins as economic commodities and symbolic entities; critiques commodification and marketing aligned with corporate interests and sustainability narratives.

These disciplinary differences reveal potential blind spots and fragmentation in protein transition research. While each discipline provides valuable insights, their isolated approaches risk overlooking key interconnections across environmental, social, and policy dimensions of food systems (Jager, 2024). For example, Behavioral Economics may overlook structural barriers to behavior change such as income constraints or limited access to alternative protein sources, while Nutritional Sciences may neglect the socio-cultural dimensions of eating: people do not eat protein; they eat meals within social and cultural contexts.

Furthermore, these isolated approaches fail to account for the complex interrelations within food systems, where shifts in dietary habits, agricultural practices, and economic structures are deeply interconnected. For example, introducing new crop varieties or adopting innovative methods like lab-grown meat, might affect the whole value chain, including food producers, processors, distributors, retailers, and consumers (Koole, 2022; Magrini et al., 2016). Ignoring these interdependencies may result in unintended consequences that slow or hinder the transition (e.g., focusing on the transformative power of consumers to make a change while their behaviors are largely influenced by food environments (Clapp et al., 2025; Mausch et al., 2025; SAPEA, 2020).

The study also highlights that disciplinary assumptions shape different and sometimes competing narratives about the protein transition (Fischer et al., 2024). Behavioral Economics tends to view change as driven by individual consumer choices (e.g., Wendin & Nyberg, 2021), a vision of change very close to the consumer narrative identified in the **Narrative Paper** (Paper 1), whereas Political Economy focuses on structural barriers and power dynamics (e.g., Howard et al., 2021), closer to the socio-technological narrative. For this latter perspective, regulatory frameworks, unequal access to financial and political resources, and corporate influence shape the pace and direction of change (Vallone & Lambin, 2023). Political Economy therefore considers food system transition as a power-driven process that requires reshaping economic and institutional structures.

The protein transition, like many pressing challenges of the century, involves complex, interrelated challenges that span environmental, nutritional, economic, ethical and social dimensions (Pascucci, 2025). These challenges can hardly be adequately addressed by disciplines working in isolation increasing call for cross-disciplinary approaches (Cronin et al., 2024; Pascucci, 2025). Thereby, this paper advocates for greater cross-disciplinarity in protein transition research. As a first step, fostering collaboration across disciplines can enhance

problem-solving by integrating diverse perspectives, leading to a more comprehensive understanding of how food systems function and evolve (Jager, 2024). Collaboration can also help identify potential trade-offs and prevent one-dimensional solutions that might create new problems elsewhere (Jager, 2024). Drawing on recent literature and reflecting on the gaps revealed by the study, this paper argues that cross-disciplinarity can take different forms, ranging from “weak cross-disciplinarity”, which involves pragmatic collaborations that maintain disciplinary boundaries, to “strong cross-disciplinarity”, which entails deeper, reflexive engagements that challenge traditional academic divisions. While “strong cross-disciplinarity” can be more time-consuming and complex, requiring researchers to critically examine their own assumptions and engage with unfamiliar perspectives, “weak cross-disciplinarity” could be more feasible in the short term. It also has the potential to depend on key transition agents—facilitators who help bridge gaps between disciplines. Key questions here are: who should these facilitators be? What are the specifications of their mission? What tools can they use to bridge the gaps?

This study underscores the challenges and opportunities in bridging the divides between disciplines like Behavioral Economics, Nutritional Sciences, and Political Economy within the context of the protein transition. Each discipline brings distinct problem framings, methodologies, and assumptions that shape their research boundaries and influence their proposed strategies for advancing the protein transition. These differences in framing often stem from competing visions of future development, including the anticipated changes and key challenges to address.

Moreover, these divergent perspectives extend beyond academic discourse and can shape policy debates, at times hindering the formulation of coherent strategies. To address these challenges, this study underscores the need for cross-disciplinary approaches. Integrating diverse viewpoints can deepen understanding and contribute to a more holistic vision of the protein transition.

To our knowledge, this is the first paper to examine the disciplinary contributions to the protein transition, paving the way for a broader reflection on how a more holistic and comprehensive vision of this transition can be developed within academia.

One limitation of this study is its focus on three specific disciplines. To illustrate the dynamics of the protein transition, we selected Behavioral Economics, Nutritional Sciences, and Political Economy. These disciplines were chosen based on multiple criteria: 1) their alignment with the

narratives identified in the **Narrative Paper** (Paper 1), 2) their well-defined academic scope, 3) the availability of a substantial body of literature base on the protein transition, and 4) the distinct perspectives they provide on different aspects of the food system. Nevertheless, this selection remains illustrative rather than comprehensive. For instance, Behavioral Economics could also be considered a subdiscipline of economics, while other disciplines, such as agronomy, psychology, and economics, along with their subdisciplines, could also offer valuable additional insights.

A Restatement of the protein transition

A protein transition is widely promoted as a pathway toward sustainable food systems. However, its implementation remains contested, shaped by competing narratives (**Narrative Paper** (Paper 1)) and divergent interpretations of sustainability, health, equity, and economic viability (Baudish et al., 2024; Béné & Lundy, 2023). These narratives are not only driven by stakeholders' interests but are also underpinned by scientific statements, which can be selectively interpreted and used to advance specific agendas. As a result, the societal and policy debates around protein transitions are often polarized, hindering constructive dialogue and progress (iPES Food, 2022; Katz-Rosene et al., 2023; van Eeten, 1999).

The protein transition is inherently interdisciplinary, spanning domains such as nutrition, environmental science, economics, political science, and sociology. Yet, as shown in the **Disciplinary Paper** (Paper 3) academic research often remains siloed, producing fragmented bodies of knowledge that fail to fully capture the complexity and interconnections of protein-related challenges.

To address this, the current paper adopts a Restatement approach to synthesize scientific insights across disciplines and critically reflect on the implications of fragmented evidence for the protein transition. The Restatement provides a comprehensive and accessible overview of the evidence base about protein transition through a structured analysis of 68 scientific statements grouped into Background, Context, and Impacts sections. It aims to serve as a resource for researchers, policymakers, and other stakeholders engaging with the protein transition, while highlighting the importance of epistemological awareness and integrative thinking in navigating and shaping the protein transition.

The full version of this section has been published in Environmental Research Letters and is accessible using the following link: [Restatement Paper](#)

Box 4: Key terms of the Restatement Paper

Facts - statements - actions:

Multiple **facts** (e.g., “meat is a source of iron”, “ruminants can graze”) are combined into different **statements** (e.g., “reducing meat consumption risks vitamin iron deficiency”, “ruminants are essential for the maintenance of grasslands”), and fostering a specific set of statements leads to advocating certain **actions** (e.g., advising against the reduction of meat consumption, advocating for the preservation of ruminants to maintain European grasslands). The actions ultimately embody different narratives about the transition process.

Enabling/disabling factors of the transition:

Enabling/disabling factors of the transition are conditions, processes, or elements that either facilitate or hinder progress toward achieving a specific transition, such as shifts in societal systems, policies, or technologies. Enabling factors support or accelerate change, while disabling factors create barriers or slow down the transition.

Politics of evidence:

The **politics of evidence** refers to how evidence is produced, interpreted, and used within social, political, and institutional contexts to influence decision-making, shape narratives, and legitimize specific actions or policies (Béné, 2022). It acknowledges that evidence is not neutral; its generation and application are shaped by underlying values, power dynamics, and competing interests. This concept highlights how choices about what counts as evidence, whose evidence is considered credible, and how evidence is framed can privilege certain perspectives while marginalizing others (Parkhurst, 2017).

Working on the protein transition revealed that research in this field is both fragmented and inherently interdisciplinary. The aspiration of the Restatement as a project was to synthesize disciplinary insights into a format that bridges these disciplinary divides, maintains scientific rigor, and integrates diverse academic perspectives while highlighting areas of consensus and disagreement. In this perspective, we encountered the *Restatement* format, developed by the Oxford Martin School to synthesize scientific knowledge in areas of policy relevance of the natural sciences (Oxford Martin School, 2024). This format organizes evidence into concise, accessible statements supported by academic literature, and aims to support informed dialogue and decision-making. Although the Restatement approach was not perfectly suited to the protein transition, we selected it as the most viable option available given our objectives.

The Restatement methodology typically consists of generating evidence-based statements, assigning confidence levels, and consulting a wide range of academic and non-academic stakeholders. Given the specific challenges of the protein transition, particularly its ontological and epistemological diversity and the absence of a specific “protein transition” community, we introduced two key modifications to the methodology proposed by the Oxford Martin School. First, participation was limited to academic experts to enable critical reflection on scientific knowledge. Extending the project to non-academic stakeholders (e.g., policymakers or civil society) remains a promising direction for a potential second phase. Second, we deliberately chose not to assign confidence levels to individual statements, acknowledging the plurality of ontological and epistemological perspectives among the disciplines engaged with the protein transition. Given the absence of a single, shared standard for evaluating evidence across these fields, this approach stands in contrast to the more positivist orientation of the Oxford Martin School, which focuses primarily on natural science-related topics.

The initial draft of the Restatement was prepared by two authors drawing on their expertise and prior research. This draft was subsequently circulated to a broad range of experts identified by the team. Out of the 27 experts contacted, ten agreed to review the paper and provide comments on the various statements¹⁵. Five of these experts joined the author team, which was

¹⁵ For each section, experts were invited to assess whether it addressed all relevant aspects of the topic and to suggest any studies or perspectives that may have been overlooked. Additionally, for each statement within the different sections, experts

later supplemented by two additional scholars to enhance disciplinary breadth. Through multiple iterative rounds of review and internal peer discussion, the author team refined both the structure and content of the Restatement. Each co-author took responsibility for leading specific sections, working in pairs, with another team member reviewing the completed section. More detailed contributions are provided in [Supplementary data Restatement](#).

While the rest of the PhD primarily focused on terrestrial farmed animals, this paper extends the scope to include aquatic animal proteins, encompassing both farmed (marine or freshwater aquaculture) and wild-caught (fisheries) sources, such as fish and aquatic invertebrates (e.g., shellfish, cephalopods).

The resulting output comprises two core documents (Figure 10). The **Main Paper** reflects critically on the epistemic and institutional fragmentation of current protein transition research, while the **Appended Restatement** (the Appended document can be found as [Supplementary data](#) of the paper published in ERL) presents a structured synthesis of scientific evidence. The Appended Restatement is organized into three sections (Table 5): *Background*, which introduces protein's nutritional role and their socio-political relevance; *Context*, which addresses enabling and constraining factors; and *Impacts*, which evaluates the health, environmental, animal welfare, and economic impacts of a protein transition. Numbered statements, supported by lettered subsections with referenced evidence, allow for clarity, transparency, and ease of cross-referencing across the document.

were asked to indicate whether they agreed, disagreed, or felt not competent to judge, and to provide comments and additional references explaining and supporting their choice.

Table 5: Structure of the Restatement by main sections, addressed topics, and the number of statements included in each section.

	Section	Topics	Number of statements
Background	n/a	Introduction to protein, historical perspective.	5
Context	Economic	Agricultural economy in the EU, economic role of the livestock sector, subsidies from the Common Agricultural/Fisheries Policy, protein imports, protein-rich crops sector.	4
	Political/power	Agricultural and fisheries policies and their conflicting objectives, EU policies and national initiatives supportive of a protein transition, inequity in food distribution, consolidation of power, spread of (mis)information.	10
	Consumer	Protein consumption in the EU, drivers for consumer preferences and choices between protein sources, willingness for dietary change, gap between dietary intentions and eating habits.	5
	Occupational health	Physical and mental health hazards for livestock and arable farmers, and fishermen, concerns for slaughterhouse employees.	4
Impacts	Human health	Protein recommendations, current protein intake, animal-source protein vs plant-source and novel proteins, micronutrients from protein foods, non-communicable disease risks from protein foods, food safety.	10
	Environment	Methods for measuring environmental impacts, comparison of protein sources on their global warming potential, nitrogen, land and water use, positive and negative impacts on biodiversity.	17
	Animal welfare	Different views, indicators and tools, most concerning welfare issues, slaughterhouse considerations.	7
	Economy	Changes and opportunities for employment in alternative proteins, a just transition for farmers, affordability of plant-based diets, market interventions.	6

Figure 10 provides a visual overview of the paper's structure, highlighting the division between the Main Paper and Appended Restatement, and illustrating how each document contributes to the dual objectives of synthesizing scientific evidence on the protein transition across various contextual and impact dimensions, and critically examining the impacts of the fragmented nature of that evidence.

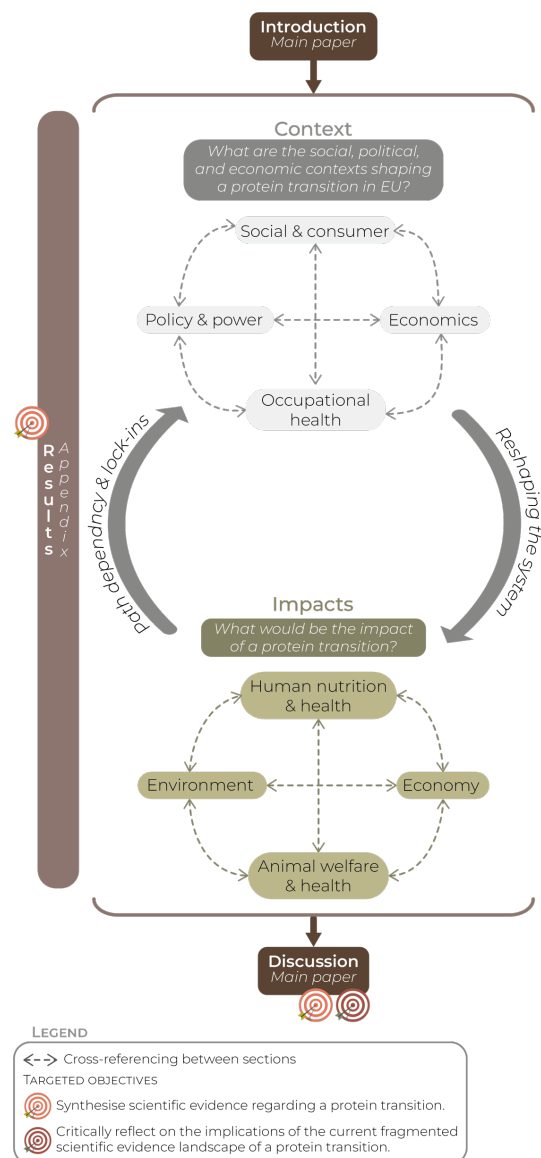


Figure 10: Overall paper structure, divided among the Main Paper and Appended Restatement and their contribution to the two objectives of the paper: (1) synthesizing scientific evidence regarding a protein transition and (2) critically reflecting on the implications of the current fragmented scientific evidence. The middle part of the figure describes Appended Restatement separated in four Context sections (linked to topics that currently shape the protein transition) and four Impact sections (linked to topics that a protein transition would have on the system, potentially reshaping the current system).

The first main result concerns the role of terminology in the protein transition debate. In particular, the paper highlights how terminology shapes how food system challenges are framed, perceived, and addressed (Baudish et al., 2024; Guthman et al., 2022; iPES Food, 2022). The Restatement process surfaced recurring concerns about the several terms limitations. Specifically, “protein transition” tends to reduce food systems to protein delivery systems, neglecting broader nutritional, cultural, ecological, and social dimensions (Guthman et al., 2022; Leroy, Beal, et al., 2022). This reductionist framing risks distorting the understanding of food

system sustainability, particularly by sidelining the importance of dietary diversity (Bianchi et al., 2022; Allegretti & Hicks, 2023). In high-income countries, the term is especially problematic as it continues to center protein with a focus on substitution even though sustainability often requires reduced consumption of protein-rich animal products (Duluins & Baret, 2024b; van der Weele et al., 2019). Furthermore, public discourse framed around individual choices (e.g., “should we eat less meat?”) can obscure the political and structural dimensions of food systems transition (Chatterjee & Subramaniam, 2021). The paper also emphasizes that meanings and implications of a protein transition vary significantly across geographies. While this Restatement focuses on the EU context, low- and middle-income countries face very different challenges, such as undernutrition, poor food accessibility, and diverse cultural and religious food norms (Adesogan et al., 2020). These regional differences underscore the need to recognize multiple, context-specific protein transitions (Simon, Gerwien, et al., 2024). Finally, terminology plays a strategic role in shaping views. Terms like “alternative proteins” can reinforce the primacy of animal protein, presenting these products as replacement options (Kanerva, 2021). In contrast, framing debates through broader terms like “food systems transitions” invites more inclusive, transformative, and fair-oriented pathways—better suited to address the complexity and diversity of global food systems (Baudish et al., 2024; Jenkins et al., 2024; Stirling, 2015).

The second main result is that the Restatement process synthesized diverse scientific perspectives and yielded three key insights regarding the role of evidence in debates surrounding the protein transition. Firstly, it became evident that genuinely disputed facts are relatively rare. For the majority of statements examined, scientists reach a consensus, or at least a shared understanding of where the limits of current knowledge lie. Where disagreement did exist, it was usually due to a lack of comprehensive or robust data rather than to fundamental rifts within the scientific community. Nevertheless, some scientific disagreements persist, often stemming from divergent ontologies, fundamentally different assumptions about how food systems function, as well as gaps in available data, contradictory findings or the dismissal of certain studies on the grounds that they are ‘not robust enough’ to support particular positions. The second insight concerns the politics of evidence and the selective combination of facts. A recurring challenge in the protein transition debate is not the absence of evidence, but it is strategic mobilization (Wood et al., 2025). Individual facts coming from different disciplines, such as “meat is a source of iron” or “ruminants can graze on marginal land”, are often selectively assembled into narratives that support specific agendas (Figure 11). These narratives, while often

based on statements that may be factually correct or not overtly inaccurate, are strategically deployed in a sequence of arguments to support specific conclusions or outcomes. In this process, the nuance or context originally associated with the statements is frequently lost or ignored, allowing the narrative to advance a particular agenda that may be disconnected from the complexities of the underlying evidence (Torpman & Röö, 2024). This is problematic when these narratives shape public and political debates in ways that sustain the status quo. For example, claims emphasizing the nutritional value of red and processed meat are often used to oppose calls for dietary change, thereby limiting opportunities for transformative shifts in diets and food systems (Clare et al., 2022). In doing so, they overlook extensive scientific evidence and repeated recommendations advocating for reduced meat consumption alongside increased intake of fruits, vegetables, and nuts (Rockström et al., 2025).

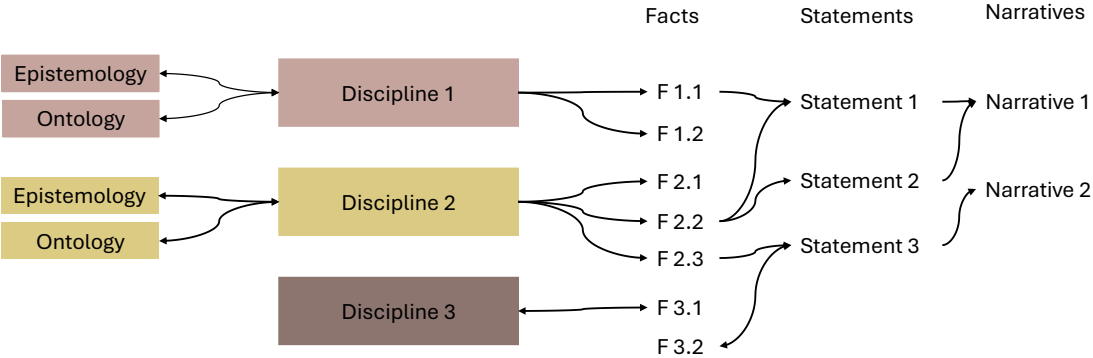


Figure 11: Certain facts are selectively combined into statements that support different narratives

The paper highlights how public discourse around the protein transition is frequently dominated by framings that align with the interests of powerful stakeholders, with selective use of evidence occurring among actors with clear political or financial interests, such as corporations, lobbyists, and industry associations. For example, the emergence of plant-based and lab-grown protein alternatives is often framed as a “silver-bullet solution” to environmental challenges (Sexton et al., 2019). These framings, heavily championed by companies invested in these technologies, emphasize their potential environmental benefits while overlooking more systemic issues such as overconsumption, unequal access to healthy diets, structural inequities in the food system, and the underlying power dynamics that shape whose interests are prioritized in defining options (Baudish et al., 2024; Duluins & Baret, 2024b). Similarly, meat and dairy industries

construct their narratives, selecting specific statements, such as the nutritional value of animal-source foods or the ecological functions of grazing systems (Leroy, Abraini, et al., 2022; Leroy, Beal, et al., 2022; Leroy & Ederer, 2023). These claims, while based on factual elements, are often used to deflect criticism and obscure the wider environmental, health, and ethical implications of intensive livestock production systems (Torpman & Röö, 2024).

Notably, the selective use of evidence is not limited to industry or policy actors; it is also evident within the scientific community itself. Research funding from private companies can shape which narratives gain prominence, creating potential biases in the interpretation and dissemination of scientific findings. A prominent example is the Dublin Declaration of Scientists on the Societal Role of Livestock, initiated during the International Summit on the Societal Role of Meat in Dublin in 2022. While the declaration highlights the societal value of livestock, emphasizing its role in addressing nutritional needs and supporting rural economies, it has faced criticism due to the affiliations of its signatories and the potential influence of the meat and dairy industries (Krattenmacher et al., 2024; Turnhout et al., 2021). Critics contend that these industry ties may shape the perspectives presented, privileging sectoral interests over broader environmental and health concerns. These blurred boundaries between science and industry raise important questions about scientific independence, the politics of evidence, and how selectively mobilized facts shape both public debates and policy decisions on the protein transition (Clapp et al., 2025).

Finally, perhaps the most enduring challenge lies in integrating partial disciplinary perspectives. While much research on the protein transition is rigorous within individual fields, few disciplines alone can address the systemic complexity of food system transformations or anticipate the rebound effects of solutions that initially appear beneficial. For instance, nutritional science may advocate reducing red meat consumption for health reasons, while agroecology emphasizes maintaining a baseline population of ruminants to sustain Europe's grassland ecosystems. In this context, it remains unclear whether reduced consumption should—or could—translate into reduced production, and what the appropriate production levels would be. Addressing this challenge requires attention at two distinct levels. The first concerns coordination within the scientific community: developing shared messages, fostering interdisciplinary dialogue, and creating mechanisms for synthesizing insights across disciplines, as exemplified by initiatives like the EAT-Lancet Commission. The second concerns the institutional, political, and governance frameworks that make it possible to translate these integrated scientific insights into actionable

decisions—providing the structures and processes through which trade-offs can be evaluated, prioritized, and implemented in a context-sensitive and policy-relevant manner. The limitation is therefore not simply a lack of knowledge, but the absence of both epistemic coordination and institutional mechanisms capable of bridging disciplinary insights with practical decision-making.

The paper argues that (more) scientific evidence is unlikely to drive transformative change because the debate is not just about data, it is about power, values, and priorities. Decisions about food system transitions are heavily influenced by political, economic, and social forces rather than simply dictated by the best available evidence (Parkhurst, 2017). Consequently, the paper calls for more transparent and interdisciplinary approaches that not only acknowledge the value-laden nature of sustainability debates but also ensure that proposed options are better aligned with the underlying problems they aim to address (Benton, 2023; Verkuijl et al., 2024).

The Restatement offers a valuable first step in synthesizing existing knowledge on the protein transition. Yet it should be regarded as a foundation rather than a final product.

To our knowledge, this is the first Restatement on the protein transition. By bringing together multiple dimensions of the debate, the paper aims to provide scientists new to the field a structured overview of the field, allowing for understanding and interpreting current debates and scientific evidence on the protein transition. More broadly, it is intended to support all actors involved in studying, discussing, and making decisions related to a protein transition within the context of sustainable food systems in the EU and beyond.

The Restatement methodology supports clarity by organizing insights into structured statements. While this improves accessibility, the act of classification inevitably introduces boundaries that may obscure system interconnections, trade-offs, and interdependencies. The resulting synthesis is thus necessarily partial and simplified. In addition, the expertise represented among the co-authors was not exhaustive. Some disciplines, notably economics and psychology, were absent, not by design but because we were unable to secure experts willing to contribute the required time.

Limitations also extend to the statements themselves. Reviewers could not reasonably verify all 68, and their formulations reflect contributors' diverse disciplinary backgrounds. Moreover, we did not follow a systematic method to select the studies included in this paper, which may invite criticism regarding the choices made and raise questions about the quality and

representativeness of the included evidence. This highlights the iterative nature of Restatements: future versions could be hosted online, revised continuously as new evidence emerges, and expanded to include perspectives from currently absent disciplines. Equally important is opening contributions beyond academia, to integrate the knowledge of policymakers, civil society, and other stakeholders.

Finally, although the Restatement effectively compiles scientific evidence and facilitates cross-referencing across disciplines, it does not map the interconnections between system components or examine trade-offs within the protein transition. For example, while it synthesizes knowledge on health and environmental considerations, it does not address how these factors should be balanced in the pursuit of a healthy and sustainable diet, nor the potential trade-offs arising from prioritizing one dimension over another.

The paradoxes of the protein transition

Scientific consensus is clear: transforming food systems is essential for meeting climate, biodiversity, and public health goals (Willett et al., 2019). Central to this transformation is the protein transition, defined as the shift away from unsustainable patterns of animal-based overproduction and overconsumption toward alternative protein (Duluins, Cardinaals, Potter, Espinosa, Sahlin, et al., 2025). Within the protein transition literature, it is often assumed that changing dietary patterns and shifting to the consumption of alternative proteins is sufficient to drive this transition.

This paper questions that assumption by examining the risks associated with solution-driven approaches when they are treated as substitutes for systemic thinking. By exploring the paradoxes such approaches can create, this section investigates the complex interplay between solutions, narratives, and actors involved, aiming to deepen our understanding of the challenges and unintended consequences that arise when systemic issues are addressed by isolated fixes but also how they risk overlooking the deeper structures and systemic issues these solutions claim to address (Mausch et al., 2025).

The full version of this section has been published in Nature Food and is accessible using the following link: [Paradox Paper](#)

Box 5: Key terms of the Paradox Paper

Paradox: A **paradox** occurs when contradictory elements coexist, creating tension within the system (W. K. Smith & Lewis, 2011). In this paper, we define a paradox as the outcome of these opposing forces, which push the system toward conflicting configurations or directions, resulting in a mismatch between the issues at stake and the solutions put forward.

Path-dependency: The concept of **path dependency** illustrates how established trajectories and past choices significantly shape present and future possibilities for development, casting long shadows over contemporary decisions and direction (Kay, 2003; Peters et al., 2012; Vanloqueren & Baret, 2009).

Protein regime: The term "**regime**" refers to the established and stable socio-technical system shaped by cultural norms, worldviews, and embedded structures such as physical infrastructure, laws, regulations, and policies (Geels, 2002, 2005, 2011). In this PhD, we define the protein regime as the dominant ways of producing and consuming proteins, shaped by these cultural norms, worldviews, and structural factors. This regime reflects the current practices and frameworks that govern how proteins are produced, distributed, and consumed, influencing both societal behaviors and policy decisions.

Efficiency: **Efficiency** refers to the reduction of inputs (e.g., energy, materials, land) per unit of output. It is typically achieved through technological improvements and is widely embraced in business and policy as it aligns with economic goals like cost reduction and profit maximization (Rudolf & Schmidt, 2025). Efficiency serves both as a metric of production performance and as an indicator of environmental effectiveness, particularly in efforts to reduce resource use and emissions per unit produced.

Sufficiency: **Sufficiency** involves the deliberate limitation of consumption and production, either voluntarily or through regulation, with the aim of reducing absolute resource use (Allievi et al., 2015; Cabeza et al., 2022; Princen, 2003). It represents a shift away from consumption-driven growth models, aligning with alternative economic paradigms such as degrowth and steady-state economics (Huber et al., 2020; Kerschner, 2010; Samadi et al., 2017).

Through 19 expert interviews and an exploration of grey and scientific literature, we employed an inductive, iterative process to identify, refine, and classify key paradoxes at the heart of the protein transition debate, resulting from the interplay of path dependencies, stakeholders' interests, and narratives. The experts were selected based on their areas of expertise and disciplinary background, and to ensure a balanced representation of perspectives from academia, civil society, and policy. Table 6 provides an overview of the selected experts, including their sector, institutional affiliation, status, and primary areas of expertise.

Table 6: Overview of the selected experts for the Paradox Paper

Sector	University/Organization	Expertise
NGO	Good Food Institute Europe	EU Policy, sustainable proteins, strategic relations
NGO	BEUC (The European Consumer Organization)	EU food law, food labelling, food safety, food waste
NGO	Greenpeace	Environmental policy, sustainable agriculture
Policy	European Commission	Agricultural policy, rural development
Policy	Oxfam	Sustainable food systems
Policy	European Economic and Social Committee (EESC)	Environmental policy, sustainable development
Academia	Copenhagen Business School, Consumer and Behavioral Insights Group	Consumer behavior, food systems, transformative economies
Academia	INRAE (National Research Institute for Agriculture, Food and Environment)	Agroecology, livestock systems, one health approach
Academia	Toulouse School of Economics	Environmental economics, risk analysis, policy evaluation

Academia	INRAE (National Research Institute for Agriculture, Food and Environment)	History of science and technology, agriculture and environment, agricultural and territorial transitions
Academia	Oxford University	Food systems, sustainability, climate change
Academia	University of Leeds	Food security, climate change, agriculture
Academia	Wageningen University & Research	Global nutrition, healthy diets, food systems
Academia	KU Leuven	Agricultural economics, bioeconomics, sustainable food systems
Academia	CNRS & CIRAD	Political economy, food systems, agroecology
Academia	Université de Montréal	Epidemiology, nutrition, public health
Academia	Wageningen University & Research	Food policy, public administration, governance
Academia	Trinity College Dublin	European agricultural policy, agricultural economics, international trade
Academia	University of California, Santa Cruz	Food systems, political economy, agriculture

The paper identifies three key paradoxes in the protein transition, as shown in Figure 12.

The first paradox, the substitution paradox, highlights the inconsistency of focusing efforts on replacing animal proteins with other sources, when the issue lies in over-consumption (Ververis et al., 2024). Despite global reports highlighting the environmental and health concerns of excessive animal protein intake (e.g., Willett et al., 2019), most strategies emphasize substitution rather than reduction (Smetana, Ristic, et al., 2023; van Loon et al., 2023). While health authorities recommend 0.83 g/kg/day of protein, Europeans consume an average of 1.25 g/kg/day, 0.75 g from animal sources (Figure 12) (EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA), 2012; FAO et al., 2007). The paper emphasizes that simply reducing animal protein intake by 55%, without increasing alternative sources, could shift the current 60:40 animal-to-plant protein ratio to 40:60, better aligning with sustainability and health objectives (Simon, Hijbeek, et al., 2024).

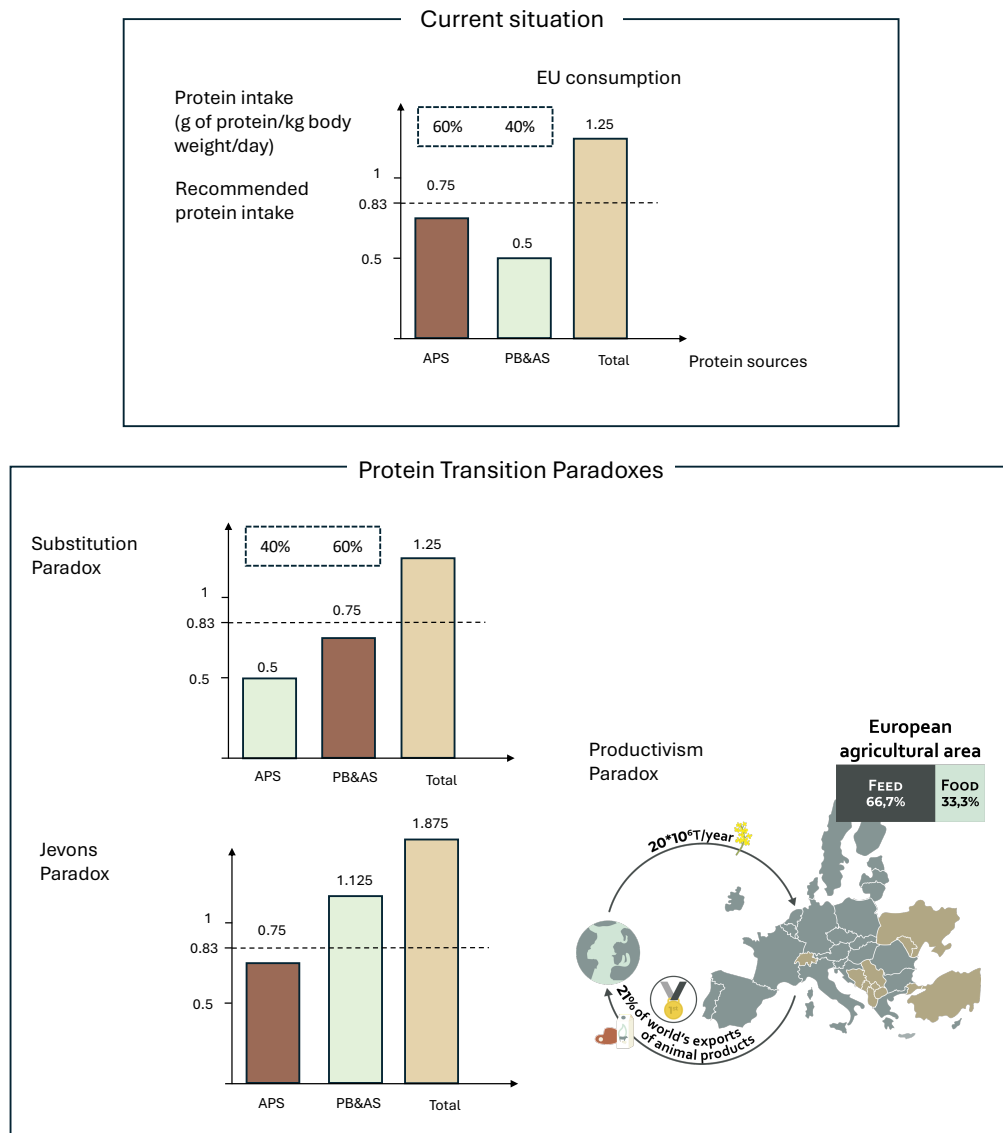


Figure 12: The left side of the figure illustrates the current state of protein consumption in Europe, where people consume approximately 1.25 grams of protein per kilogram of body weight per day, with 60% of that intake coming from animal sources. The right side of the figure highlights the paradoxes that arise from the mismatch between the proposed solutions and their intended targets. The recommended protein intake (dashed horizontal line in all plots) is from the European Food Safety Authority and Food and Agriculture Organization recommendations (EFSA, 2012, FAO et al. 2017). APS, animal protein sources (including meat from domesticated animals, fish and seafood, dairy products, eggs, and game meat); AS, alternative protein sources (including novel plant-based substitutes (often referred to as meat mimics or analogues), lab-grown proteins (such as cultivated or cellular proteins) and processed products from insects); PB, plant-based protein sources (including traditional protein preparations such as tofu and seitan, whole foods, legumes, grains, seeds or mushrooms).

The second paradox is emerging from the efforts to address the unsustainability of current protein production systems. The Jevons' Paradox¹⁶ describes the phenomenon whereby improvements in resource-use efficiency, producing the same output with fewer inputs, often lead to lower costs per unit, which can stimulate higher overall consumption and production rather than a reduction, ultimately increasing environmental impacts (Allievi et al., 2015; Freire-González, 2021). In the context of the protein transition, the Jevons' paradox highlights the risk that the development of protein sources perceived as more efficient will lead to a net increase in production and consumption, reducing or wiping out per-unit efficiency gains (Alcott, 2005; Allievi et al., 2015; Rudolf & Schmidt, 2025). This paradox illustrates why efficiency alone is unlikely to deliver absolute reductions in resource use and emissions (Benton & Bailey, 2019; Talenti, 2025).

The last paradox, the productivism paradox, results from Europe's narrative of the protein transition, which focuses on reducing dependence on imported proteins, primarily used for livestock feed (European Commission, 2018) (Figure 12). In 2023, European livestock production relied on two-thirds of the European agricultural land for feed crops, along with annual imports of 19 million tons of oilseed meals (European Economic and Social Committee, 2022). A primary objective outlined in the European Parliament resolution for a protein strategy is to boost protein self-sufficiency by replacing part of these imports with domestically grown protein-rich crops (European Commission, 2024; European Parliament, 2023). Yet, achieving this while maintaining current livestock production would require at least 5 million hectares (representing about 5% of Europe's agricultural land) redirected to protein crops, impacting land availability, costs, and sustainability (Thom et al., 2024). The productivism paradox highlights that, despite widespread protein overconsumption and a surplus of animal products that has positioned Europe as the world's leading exporter (Guyomard et al., 2021), policy efforts continue to prioritize reducing the protein deficit of the EU without re-evaluating the scale of overall animal production.

These paradoxes illustrate a broader pattern of solutionism in sustainability debates, where technical fixes are often promoted while deeper structural issues within the system are overlooked. The critique here is not targeting the solutions per se, technological and market-

¹⁶ Jevons' Paradox, introduced by British economist William Stanley Jevons in his 1865 book *The Coal Question*, describes a counterintuitive phenomenon in which improvements in the efficiency of resource use can lead to an overall increase—rather than a decrease—in resource consumption. Jevons observed that as steam engines became more efficient at using coal, coal consumption in England actually increased, because cheaper energy spurred greater industrial growth and broader use of steam technology (Jevons, 1865).

based innovations can play an important role but approaches that treat such solutions as sufficient in themselves, neglecting the wider system they operate within. Several authors have explored the risks associated with solutionism, an approach in which complex problems are treated as though they can be addressed by simple, often technological or market-driven solutions, without fully considering the underlying issues or potential unintended consequences (Benton & Bailey, 2019; Guthman & Butler, 2023). This approach can overlook deeper, systemic causes, such as social, political, or cultural factors, as well as the broader effects of introducing a solution into a complex system (Meadows, 2008). In this paper, we have demonstrated how certain options, such as emphasizing substitution or developing alternatives, can divert attention from more fundamental questions: why prioritize substitution when reduction might more effectively address the root of the problem? What are the structures, values and views that are currently favoring this overconsumption and production, and how could these be tackled? Furthermore, we highlight the potential for rebound effects, where the development of more efficient alternatives can lead to unintended consequences that counteract the intended benefits.

The three paradoxes identified underscore a recurring tendency to focus on what we want more of, such as increased alternative protein production and consumption, rather than what we need less of (Princen, 2005). In examining these paradoxes, the paper further explores who stands to benefit from the proposed solutions and why (e.g., substitution in human diets, developing more efficient alternative proteins, and increasing protein feed self-sufficiency)?

The public sector plays a crucial role in the protein transition, with its influence spanning research (e.g. through research fundings), policy, and regulation. Policy initiatives from the European Commission, including recent fact sheets on reducing the plant protein deficit in the European Union and the Farm to Fork strategy, directly contribute to these paradoxes (European Commission, 2020, 2024). While these initiatives aim to address public health and environmental and health concerns, they also (inadvertently?) align with the interests of key industry stakeholders developing these alternatives (Guthman et al., 2022). Despite efforts to diversify protein sources and reduce reliance on feed imports like soybean, the absence of explicit policies to reduce livestock numbers and impacts suggests an implicit, if not tacit, endorsement of the current state of livestock and cereal sectors, exemplifying the productivism paradox (Boezeman et al., 2023). Furthermore, European policies, bolstered by subsidies and regulatory frameworks, continue to favor animal proteins, placing alternative protein sources at a

comparative disadvantage (Vallone & Lambin, 2023). Lastly, the focus of public research and academia on dietary shifts and alternative proteins promotes them as a viable solution to environmental challenges, contributing to the substitution paradox and the risk of the Jevons' paradox (Allievi et al., 2015; Smetana et al., 2015; E. Smith et al., 2024; Thornton et al., 2023).

The public sector may intentionally preserve ambiguity or avoid redefining the vision for the livestock sector, as doing so would entail confronting the politically sensitive and economically complex realities of European agriculture. With approximately 2.6 million farms are specialized in livestock and 60% of cereal acreage is used for animal feed, addressing the environmental impact of livestock production would require a radical transformation of crop production, supply chains, and rural economies (Matthews et al., 2023). Shifting away from this system would require significant changes in crop production and supply chains, such as expanding the cultivation of protein crops, which could disrupt established agricultural economies (Hristov et al., 2024; Rieger et al., 2023). Such a shift is politically unattractive, as it will come with winners and losers as some stakeholders would suffer from reduced reliance on livestock sectors, while others could benefit from innovation and diversification in crop production (Rieger et al., 2023). Furthermore, policies that fail to directly target livestock numbers or that maintain subsidies for animal-based proteins benefit the existing livestock and cereal sectors, allowing them to preserve the status quo (Vallone & Lambin, 2023). A key underlying factor is Europe's dominant position as the world's leading exporter of animal-based products (Guyomard et al., 2021). By emphasizing dietary substitution and protein sources diversification, policymakers can sidestep deeper structural changes in favor of easier, less contentious solutions that emphasize what we want more of, rather than confronting the harder question of what we need less of. However, this raises the question of whether such a lack of reconsideration of the future of forward livestock farming is really viable in a context where certain farmers, particularly livestock beef farmers, are struggling (Duluins et al., 2022), where trade agreements remain highly contested (Rankin & Rogero, 2024), and where farmer protests driven by multiple grievances have profoundly shaped the political landscape in 2024 (Candel, 2024).

For the private sector, agri-food companies are responding to the growing demand for alternative proteins and shifting dietary preferences by diversifying their portfolios to include both animal-based and alternative proteins (Guthman et al., 2022). This strategy not only allows companies to capitalize on changing consumer trends and cater to a variety of global tastes and dietary needs, but also minimizes risks associated with potential declines in demand for animal

protein (Howard et al., 2021). By expanding into the growing alternative protein market and maintaining a broad offering, these companies position themselves to secure market share while shielding their business from market fluctuations (Howard, 2022). Retail sectors follow suit, offering consumers a wide variety of protein choices.

This trend aligns well with the substitution paradox, where new alternatives do not replace animal proteins but instead diversify the protein options available, creating a higher total demand for protein (Trewern et al., 2021). In economic terms, the growth of the alternative proteins market does not reduce overall protein consumption but rather contributes to an increase in the overall market for protein, which aligns with the logic of Jevons' paradox (Guthman et al., 2022; Jevons, 1865). For the private sector, advocating for reduced demand, such as policies to reduce livestock numbers, curb current consumption patterns, or ban meat advertising, is not a marketable or economically viable option within a growth-driven framework (Jackson, 2009). This raises important questions about the differing roles of entrepreneurs and policymakers. Entrepreneurs typically operate within existing market rules and are incentivized to innovate while staying competitive in a growth-centric system. Policymakers, by contrast, hold the authority to reshape those rules, reconsider structural constraints, and redefine the paradigms guiding the food system.

The paper concludes by examining the narratives that support and justify the various paradoxes, highlighting the discrepancy between the issues at stake and the proposed solutions. Specifically, we explore how narratives of efficiency, comparative advantages rooted in past policies, food security, food sovereignty, and the risk of leakage effect reinforce these paradoxes. For each narrative, we disentangle the core arguments showing the limits of their validity and the potentially overlooked systemic aspects. Taking the food security narrative as an example, the argument for maintaining current levels of animal production in Europe often emphasizes its contribution to global food security through exports (Candel, 2014; Sonnino et al., 2016). However, this narrative conflicts with the broader definition of food security endorsed by the scientific community and international organizations, which focuses on ensuring physical and economic access to sufficient, safe, and nutritious food for all (FAO, 2024b). By prioritizing well-stocked shelves and exports, this narrative overlooks that food security is not just about availability; it also relies on accessibility and utilization, both of which are largely determined by deeper structural issues like poverty, environmental pressures, land access, and inadequate

infrastructure, where the root of the problem often lies (Misselhorn, 2005; Pistrup-Andersen, 2009).

This section examines the risks of solution-driven approaches, highlighting the paradoxes they create and their broader implications. The critique developed here is not directed at solutions themselves, but at *solutionism* as the tendency to treat certain solutions as substitutes for systemic approaches. Rather than testing causal relationships, the analysis assesses whether particular transition pathways are coherent with the problems at stake when viewed through a systems perspective. We explore how different narratives frame issues and solutions, who mobilizes them, and the broader objectives they serve. This allows for a deeper understanding of how systemic challenges are represented and acted upon. By unpacking these dynamics, the paper reveals the unintended consequences of seemingly straightforward fixes and offers a more nuanced perspective on navigating complex transitions.

To our knowledge, this paper is among the few that critically examine the current trajectory of the protein transition in the EU, reflecting on the proposed solutions and their potential to drive meaningful change.

Limitations of this paper include the non-exhaustive nature of the list of paradoxes presented, as well as the use of an inductive approach and a perspective-based framework. As a perspective paper, the aim is to offer interpretive insights rather than provide a comprehensive empirical analysis, which has implications for the generalizability of the findings. The scope is further restricted to the European Union to account for path dependencies and lock-in dynamics specific to this context. Additionally, the choice of interviewees was limited to academic and policy experts, with no direct representation from industry actors, which may have influenced the captured perspectives and constrained the range of insights regarding practical implementation of solutions.

Limitations of the PhD

Several limitations of this PhD should be acknowledged. First, the analysis focused exclusively on peer-reviewed scientific literature, thereby excluding grey literature that could have provided valuable insights into societal and policy narratives. For example, examining NGO websites, policy briefs, or social media debates might have revealed different framings of the protein transition than those found in academic sources. As a result, the thesis primarily reflects scientific narratives rather than broader societal discourses.

Second, even within scientific literature, the scope was limited to published journal articles. This choice has disciplinary implications, as certain disciplines, particularly in the social sciences, tend to privilege books and monographs as key outlets. Consequently, some perspectives may be underrepresented.

Third, the focus on the protein transition as a specific concept introduced additional limitations. A significant body of literature addresses issues closely related to livestock production, alternative proteins, or dietary shifts without explicitly using the term “protein transition”. This made it challenging to establish clear connections between the broader concerns associated with livestock and the emerging concept of the protein transition. As a result, some relevant studies and debates may have been overlooked, which constrained the scope of the analysis.

Fourth, the interviews conducted were predominantly with academic experts, with comparatively fewer voices from industry. This imbalance likely influenced the perspectives captured and limited the range of stakeholder insights. Relatedly, the study paid little attention to what has been described as the “missing middle”: actors situated between producers and consumers, such as processors, retailers, and traders. This gap partly reflects the limited attention these actors have received in the scientific literature on the protein transition.

Fifth, empirical work in this PhD was limited. While this represents a limitation, it also reflects a deliberate choice: the focus was on adopting a systems-oriented perspective capable of integrating insights across disciplines and domains, rather than generating new empirical data. Conducting empirical research at this level would have posed significant methodological challenges, and it was unclear whether it would have added more value than the conceptual and integrative approach pursued here.

Finally, while the thesis touches on issues of power dynamics within and beyond academia, these were not its primary focus. Further research could explore more systematically how power relations shape the framing, uptake, and implementation of the protein transition.

Chapter 4: The Reflection chapter

This chapter offers a critical reflection on the broader insights of this PhD, arguing that the protein transition is not merely a technical or behavioral challenge but a deeply political, epistemic and systemic process. The chapter unpacks the underlying tensions, framings, and institutional dynamics that shape which transition pathways are promoted, and which remain marginalized¹⁷.

The discussion is organized around two main overarching themes: (1) the coexistence and competition of narratives¹⁸, highlighting how different visions of change compete for legitimacy and resources, in academia and beyond; and (2) the implications of siloed disciplinary perspectives for the protein transition.

Taken together, these themes highlight that understanding the current and future trajectories of the protein transition requires unpacking the values, power dynamics, and institutional logics that shape what is researched, funded, and imagined as desirable futures.

Narratives as vectors of influence

At the outset of this PhD, the protein transition was conceptualized as an emerging research topic shaped by societal debate, policy attention, and evolving scientific paradigms (Béné & Lundy, 2023; Hundscheid et al., 2023; Onwezen et al., 2022). One of the key observations of this research is the coexistence of protein transition narratives within academia, each representing distinct visions of how change should unfold (Duluins & Baret, 2024a, 2025). These narratives not only coexist but also compete both discursively and materially for influence, legitimacy, and access to resources, such as research funding (Garcia & Sanz-Menéndez, 2005; Stirling, 2015; Teixeira et al., 2022).

The competition among narratives is not evaluated solely against merit or evidence. Dominant narratives gain traction through power relations, institutional alignment, and discursive legitimacy (Bahrami, 2025; Duluins & Baret, 2024b). The framing of what counts as ‘good science’

¹⁷ In this chapter, we refer to the papers by citing them according to the APA norms rather than calling them “The Narrative Paper” (Paper 1). These references can be found in Bibliography. Phrases like “the Restatement Paper showed that” were avoided in favor of proper citation placement, with references included directly after the relevant sentence.

¹⁸ In this paper, a narrative is defined by three key elements: a driver of change (the central issue to be addressed), a vision of a desirable future, and one or more pathways encompassing solutions for achieving that future. As such, narratives represent different perspectives on food system transformation—what the ideal future looks like and how to reach it.

shapes which visions of change become actionable and which are sidelined (Leach et al., 2010). This raises the question of whether dominant narratives emerge primarily from their scientific robustness or from the political economy of research including what gets funded, by whom, and with what expectations. Funding priorities, in this sense, can operate as selective pressures that amplify certain scientific narratives of the protein transition while marginalizing others.

Beyond the politics of knowledge production¹⁹, the narratives identified in this research are often emotionally and ideologically charged (Bilandzic et al., 2020). They are grounded in deeply held convictions about sustainability, justice, and the role of science in society (Baudish et al., 2024; Béné & Lundy, 2023; Saltelli et al., 2020). Consequently, they compete not just for funding but also for recognition and ontological legitimacy. This affective and existential dimension underscores why debates around the protein transition are often so polarized: they are not only about how food systems should change, but also about whose vision of change is rendered visible, legitimate, and actionable (Torpman & Röö, 2024). Who gets to define the problem, and therefore the solution, matters (Bacchi, 2019; Leach et al., 2010).

This struggle for narrative legitimacy is not without long-term consequences. When particular narratives attract preferential investment and institutional support, they can reinforce their own dominance over time, marginalizing alternative transition pathways and narrowing the spectrum of future possibilities (Cleaver & Tom, 2008; Cowan & Gunby, 1996; Vanloqueren & Baret, 2009). Such dynamics have been well documented in agricultural research, where trajectories like genetic engineering have benefitted from disproportionate support compared to alternatives such as agroecology (Vanloqueren & Baret, 2009). Similar patterns emerge when comparing pest control strategies, where reinforcement mechanisms have contributed to the progressive dominance of chemical pesticides over alternatives such as integrated pest management (IPM) (Cowan & Gunby, 1996). These structural and cognitive factors have created a dominant technological regime that not only constrains the development of agroecological or IPM alternatives but also sidelines them as viable and legitimate pathways (Vanloqueren & Baret, 2009).

¹⁹ The politics of knowledge production refers to the ways in which power, interests, and values shape what knowledge is produced, whose knowledge is considered legitimate, and how knowledge is used in decision-making. It highlights that knowledge is never neutral: it is influenced by funding priorities, institutional settings, cultural contexts, and political agendas.

From narrative competition to structural lock-in: power dynamics in the protein transition research

In line with these observations, this PhD research confirms that while the concept of protein transition is still in an early and formative stage, marked by the coexistence of multiple narratives, two narratives increasingly dominate the discursive and material space (Duluins & Baret, 2024a). The first is a consumption-centered narrative, which emphasizes individual dietary change, often through nudges, education, or incentives, as the primary lever for transition (e.g., Onwezen et al., 2021; Siddiqui et al., 2022). The second, is a techno-centric narrative, which prioritizes the development and scaling up of alternative protein technologies such as plant-based analogues or cultured meat (e.g. Guthman & Biltekoff, 2021; Lurie-Luke, 2024). These narratives gain visibility and institutional weight not necessarily because they are more valid, but because they align with powerful research communities, funding structures, and business models (Duluins & Baret, 2024b).

At the science policy interface, this suggests a potential link between scientific narratives and dominant political discourses in which research agendas that reinforce incumbent logics, such as those compatible with technological substitution or system optimization, tend to have a better access to political arenas, and receive greater funding and political support. While this relationship has not been empirically tested within the scope of this PhD, one way of exploring it in future work would be to investigate systematically the funding patterns of protein transition research, identifying which narratives and approaches attract investment and support from public and private bodies. In parallel, access to political arenas could be examined by analyzing attendance and participation in relevant meetings, conferences, or advisory events, providing an empirical measure of how different research narratives and disciplinary backgrounds are represented in decision-making spaces (Candel & Daugbjerg, 2025).

This reflection can be extended to the type of knowledge being produced. Some disciplines and communities more readily with the “instrumental” side of knowledge production²⁰ (Cleaver & Tom, 2008), especially when their approaches resonate with dominant policy framings. Research that generates solutions easily translatable into policy tends to be rewarded with greater funding,

²⁰ In their paper, Cleaver & Tom (2008) distinguish between instrumental knowledge, oriented toward problem-solving within established systems, providing evidence, tools, and methods to make existing practices more efficient, effective, or predictable and reflexive knowledge, which challenges the goals, boundaries, and assumptions, drawing attention to underlying values, power relations, and unintended consequences.

visibility, and influence, reinforcing its dominance over more critical or exploratory approaches. This dynamic is compounded by the Matthew effect (Merton, 1968): prominent disciplinary or epistemic communities²¹, such as economists in the context of the protein transition, accumulate greater resources and authority over time, while others, such as agroecology, sociology, or political ecology, struggle to gain epistemic authority and shape the definition of credible knowledge (Merton, 1968). Taken together, these mechanisms highlight that the politics of protein transition research operate not only between academia and policy, but also within academia itself, where disciplinary hierarchies structure whose knowledge and solutions are recognized and valued.

In the private sector, both the consumer and the techno-centered narratives conveniently align with prevailing business models and investment logics, enabling companies to promote innovation and shifts in consumer behavior as solutions (Duluins & Baret, 2024b; Gurung et al., 2025). The alignment between dominant narratives and prevailing economic rationales suggests that certain visions of change are more 'investable' than others, not because they are more effective, but because they better accommodate existing institutional and market logics. This convergence of epistemic authority and financial logic raises a deeper question: is it truly possible to invest in change when this would necessitate reconfiguring the overall financial paradigm on which return on investment is based? (United Nations Environment Programme, 2025)

These patterns of narrative dominance notably reflected in funding asymmetries are deeply embedded in the broader ideological and institutional fabric of the modern era. Since the post-World War II period, Western societies have largely been shaped by a modernist, neoliberal, and productivist paradigm that privileges economic growth, technological innovation, and global trade as core pillars of progress (Harvey, 2020). Within this context, agriculture and food systems have undergone profound transformations, culminating in what McMichael (2009) terms the "corporate food regime". This regime is characterized by the consolidation of agri-food power in the hands of transnational corporations, the commodification of food and land, and the subordination of ecological and social goals to market logics (McMichael, 2009). Clapp (2018, 2022) similarly documents the corporatization of food and its alignment with neoliberal governance, which has restructured global food systems to prioritize efficiency, profit, and scale

²¹ Epistemic communities can be understood as networks of professionals with shared causal and normative beliefs, a consensual knowledge base, and a common policy enterprise (Cleaver & Tom, 2008).

over resilience, equity, or sustainability. The result is a form of “corporate occupation” of both landscapes and imaginations, where dominant actors and paradigms not only control material flows but also shape the very terms of what is seen as viable, rational, or innovative (Lang & Heasman, 2015).

In the context of the protein transition, corporate occupation materializes in the types of transition pathways being invested. For example, this research highlighted how behavioral economists tend to advocate for consumer behavior change, rarely (at least openly in their research) questioning or reconfiguring the underlying structures of the food system or considering broader systemic effects (Duluins & Baret, 2025). As a result, change is conceived from within the logic of the current market paradigm, reflecting a form of alignment by design between behavioral economics, market-based governance, and corporate interests.

These reflections call for a broader reconsideration of the role of scientific disciplines in shaping sustainability transitions (Pascucci, 2025). When certain disciplines consistently align with dominant narratives thereby gaining greater visibility, funding, and political influence, it prompts a critical question: should society rethink how science is funded, structured, and valued? Addressing this could involve reassessing the contributions of individual disciplines, considering the phased reduction of disciplines that reinforce entrenched logics as part of an exnovation process, and investing in inter- and transdisciplinary approaches that bridge knowledge domains and are increasingly recognized as pivotal to sustainability transitions (Pascucci, 2025). Equally important is the question of who decides which disciplines are prioritized, phased out, or supported, underscoring the need for transparent, inclusive, and participatory decision-making processes that engage a diverse range of stakeholders, from researchers and policymakers to civil society and affected communities (Rinscheid et al., 2025). At the same time, disciplines are not static: they can evolve, adapt, and reinvent themselves in response to emerging societal and planetary challenges. For example, agricultural economists, long rooted in applied economics and policy impact, could expand their focus to pioneer co-created, transdisciplinary knowledge that integrates systemic, socio-ecological perspectives (Pascucci, 2025).

The innovation trap: rethinking the influence of the growth paradigm in the protein transition

Contemporary discourse on the protein transition often hinges on technological innovation as a master narrative by focusing on alternative proteins. As demonstrated in the previous section, this narrative aligns closely with an economic growth paradigm, where technological advancement is positioned as the primary lever for value creation and sustainability (Gaffney et al., 2019). Within this paradigm, innovation is expected to reconcile environmental concerns with continued economic expansion, maintaining existing patterns of production and consumption rather than challenging them (Gaffney et al., 2019; Klerkx & Villalobos, 2024).

This dominant framing, however, reflects only one vision and transition pathway for the protein transition (Geels & Schot, 2007). Alternative imaginaries rooted in justice, sufficiency, and ecological care such as agroecology, food sovereignty, and commons-based models are often sidelined (Allievi et al., 2015; Duncan et al., 2021; Wezel et al., 2009). These perspectives foreground deeper structural transformation over a scenario of technological substitution, emphasizing the need to confront the underlying institutions, policies, and cultural norms that shape food systems (Anderson et al., 2023; Baudish et al., 2024; Hundscheid et al., 2022; Vallone & Lambin, 2023).

These different transition pathways embodies a broader tension between two paradigms: one centered on efficiency and growth, within which technological innovation and substitution are positioned as key solutions, or another oriented around sufficiency and moderation. This PhD contends that the former dominates because it aligns with prevailing institutional logic rewarding scale²², efficiency, and market-based solutions (Duluins & Baret, 2024b). The latter, by contrast, lacks the institutional legitimacy and investment to become a viable alternative pathway. This is not due to its lack of scientific merit or societal relevance, but because it does not fit the evaluative frameworks that currently govern food policy, research funding, and innovation systems (Vanloqueren & Baret, 2009). However, these paradigms should not be seen as mutually exclusive. Rather than replacing one with the other, we argue that efficiency should be embedded within a sufficiency paradigm, that is, efficiency gains should serve broader goals

²² Scale here implies large-scale production or operation, favoring solutions that can be deployed widely and intensively to maximize output or efficiency.

of reducing overall resource use, moderating demand, and respecting ecological limits. Framing efficiency within sufficiency redefines innovation's purpose: from maximizing output and growth to optimizing within planetary boundaries and promoting equitable, sustainable food systems.

From this angle, this PhD argues that the protein transition risks becoming an exercise of technological substitution (Geels & Schot, 2007), while leaving core structures, values and practices intact (Duluins & Baret, 2024b). A sufficiency-based approach would imply challenging this logic by prioritizing a reduction of environmental pressures, resource extraction, and societal impacts notably by curbing demand for animal-sourced proteins, challenging overconsumption, and rethinking the policy and economic incentives that uphold high-output livestock systems (Benton & Bailey, 2019; Cabeza et al., 2022; Princen, 2005). It would also broaden the concept of innovation itself expanding it beyond technological innovation to include social, and institutional change called under a transformative change perspective (IPBES, 2019).

Yet the structural barriers for switching to a sufficiency narrative are formidable. This paradigm remains strikingly underrepresented in key policy frameworks. For example, in the *Strategic Dialogue* report guiding current negotiations for the post-2027 Common Agricultural Policy (CAP), the term *efficiency* is mentioned 11 times, while *sufficiency* appears only twice (EU commission, 2024). Sufficiency is not simply a neglected option, it is a narrative that struggles to gain traction because it challenges the very terms by which 'progress' and 'innovation' are defined (Levy & Ménascé, 2024). Unlike earlier debates that contrasted conventional and alternative technologies (Vanloqueren & Baret, 2009), sufficiency tends to render many technological solutions unnecessary or irrelevant. As a result, this narrative often falls outside the scope of mainstream funding, policy attention, or private investment despite its potential to address systemic root causes. Even if it were to gain more policy traction, however, a central challenge would remain: ensuring that sufficiency is not only mobilized as a rhetorical or discursive device, but also translated into concrete policy measures, institutional arrangements, and everyday practices that reshape food systems in practice (Candel & Daugbjerg, 2025).

Moreover, from a consumer perspective, the sufficiency pathway often lacks the affective and symbolic appeal that innovation-centered solutions offer. While new food technologies such as lab-grown meat or precision fermentation are marketed as exciting, futuristic, and aspirational (Bryant et al., 2019), sufficiency is more easily associated with restraint, sacrifice, or even regression (Grunert, 2011). Moreover, less innovative options frequently lack the aspirational branding and novelty appeal that meat and other novel alternatives possess, making them less

likely to be chosen for lifestyle or status reasons (Hartmann & Siegrist, 2017b). This narrative framing diminishes its desirability, especially in consumer cultures where novelty, convenience, and lifestyle branding are powerful drivers of adoption (Grunert, 2011; Sexton et al., 2019). As a result, technological innovation pathways not only align more easily with institutional and economic structures but also benefit from stronger cultural and emotional resonance in public discourse and marketing.

This dual advantage, structural and symbolic, creates a powerful lock-in effect. By equating innovation with technological advancement and market scalability, the current regime sidelines narratives that call for sufficiency or de-growth²³.

The growth imperative is the elephant in the room

While the analysis above identifies structural and symbolic lock-ins favoring technological innovation, a deeper, often underexamined driver is the pervasive normative assumption that economic growth is both necessary and largely sufficient for societal well-being. This assumption functions as a meta-framework shaping institutions, policies, research agendas, and market incentives, subtly yet powerfully constraining the range of plausible solutions for the protein transition, and more generally food systems transition.

Within this growth-oriented paradigm, technological innovation is valorized not merely for its problem-solving potential but because it is compatible with income generation, scale, and accumulation which are outcomes that are institutionally and politically rewarded. Universities, funding agencies, and corporate actors often equate scientific and technological outputs with economic value, reinforcing the link between innovation and growth. Policy debates, electoral campaigns, and international negotiations similarly prioritize growth metrics, preventing alternative narratives such as sufficiency from gaining legitimacy or traction, regardless of their ecological or social merits (Princen, 2005; Vanloqueren & Baret, 2009).

In other words, the lock-in of technological solutions for the protein transition is not merely a matter of vested interests, marketing, or consumer preference. It stems from an axiomatic societal assumption: that progress is measured through GDP, efficiency, and market expansion. This meta-framework renders sufficiency-based approaches inherently countercultural, as they question the very criteria by which political success, innovation relevance and social progress

²³ Degrowth is an economic, social, and political concept that advocates for the intentional downscaling of production and consumption to achieve environmental sustainability, social equity, and improved well-being.

are decided. Therefore, exploring protein transition pathways requires not only navigating technical and institutional barriers but also interrogating this deeply embedded growth imperative.

The role of vested interests in shaping narratives: science-industry-policy interfaces

Narratives are not the preserve of academia, but are embedded in networks of power and interest, where academic authority can overlap with political agendas and corporate influence. A prominent example of this overlap is the Dublin Declaration, a statement signed by several scientists that presents livestock as essential to sustainable food systems (Leroy & Ederer, 2023). Despite its framing as a neutral, evidence-based scientific position, the declaration has been widely criticized for its strong ties to industry and for advancing a narrative that downplays the environmental and health impacts of livestock production (Bryant et al., 2024; Krattenmacher et al., 2024). This example illustrates how scientific discourse can serve as a vehicle for political and economic agendas (Krattenmacher et al., 2024), with academic authority reinforcing narratives that ultimately benefit incumbent stakeholders (Duluins & Baret, 2024b).

This PhD has shown how narratives are influenced by political and financial vested interests with illustrations of how individuals, organizations or groups have a strong financial or political stake in maintain or promoting a particular status quo or outcome, because they benefit from it (Duluins & Baret, 2024b).

In the private sector, this dynamic is reflected in diverging investment strategies. Major food and agri-tech corporations increasingly entered the alternative protein sector (Guthman et al., 2022; Mylan et al., 2023). Corporations typically pursue portfolio diversification, positioning alternative proteins alongside investments in conventional animal production (Guthman et al., 2022). This approach reflects a calculated effort to capture value in a shifting market while protecting core business models. The narrative of “more choice for the consumer” becomes a convenient frame that preserve growth and continuity, while simultaneously enabling corporations to adopt the language of sustainability and align themselves with the positive public image of pursuing a protein transition (Duluins & Baret, 2024b; Guthman & Biltekoff, 2021). Start-ups, in contrast, often promote more radical narratives, imagining food futures without animals or with completely reengineered proteins (Guthman & Biltekoff, 2021; Stephens et al., 2018). However, even these actors operate within funding environments shaped by financial return, which tends to favor market-compatible, tech-driven visions. From a transition theory perspective, most start-

ups can be understood as following the technological substitution pathway²⁴: their innovations aim to replace or improve regime practices while remaining largely compatible with existing economic and institutional structures (Geels & Schot, 2007). Yet, under certain conditions, when exogenous shocks such as climate catastrophes, food safety scandals, or geopolitical disruptions destabilize incumbent regimes, start-ups may seize these openings to experiment with and amplify competing alternatives, contributing to the contestation dynamics characteristic of a de-alignment and re-alignment pathway²⁵ (Geels & Schot, 2007).

On the political level, certain narratives can be preferred as they will more easily allow to deal with the tension between the need for food systems transition, and the political reluctance to disrupt powerful economic sectors and rural livelihoods that depend on the current system (Duluins & Baret, 2024b). Although the protein transition can be seen as an opportunity to rethink more profoundly European food systems the dominant political discourse centers instead on addressing the so-called “EU protein deficit” (European Commission, 2024; European Parliament, 2023), which refers to the region’s heavy dependence on imported animal feed (Duluins & Baret, 2024b). This deficit framing not only assumes that current levels of production and consumption will be maintained or expanded but also reinforces the narrative that the EU has a responsibility to continue producing animal-based products in response to global population growth.

Beyond narratives: toward reflexive transformation

This PhD has shown that the protein transition is not simply a technical or behavioral challenge but a deeply political and narrative-driven process. Competing visions of change rooted, in divergent paradigms of innovation, sufficiency, justice, and economic rationality, struggle for discursive and material dominance within the academic, political, and corporate arenas. These narratives do more than describe reality; they actively shape it by influencing what is researched, funded, implemented, and ultimately deemed possible.

Understanding the protein transition through the lens of narrative competition reveals the underlying power dynamics at play. Narratives act both as instruments of influence and as arenas

²⁴ The technological substitution pathway involves niche innovations replacing problematic regime practices while leaving the core structures, logics, and institutions largely intact. It represents continuity through change, as new technologies are absorbed into existing economic and political frameworks.

²⁵ The de-alignment and re-alignment pathway follows major landscape shocks that destabilize the incumbent regime, creating a period of uncertainty in which multiple alternatives compete for legitimacy. This process eventually consolidates into a new socio-technical order, marking a more profound systemic restructuring.

of ideological struggle. They shape which futures are imagined, legitimized, and made actionable. As such, any serious attempt to steer the protein transition toward greater sustainability and equity must engage not only with technologies and policies, but also with the narratives that govern them.

Moving forward, a more reflexive and pluralistic approach is needed—one that recognizes the political economy of narrative formation and actively broadens the space for alternative imaginaries. This entails not just acknowledging different visions of change but reconfiguring the institutional conditions that allow some to flourish while others wither.

The impacts of siloed disciplinary perspectives to the protein transition

Why fragmentation matters?

The PhD illustrates how academic disciplines often operate in silos, and the risks this poses for advancing the protein transition (Duluins, Cardinaals, Potter, Espinosa, Resare Sahlin, et al., 2025; Duluins & Baret, 2025). For instance, while there is strong scientific agreement, especially among environmental researchers, on the need to reduce red meat consumption in high-intake regions (Andrews et al., 2025), proposals to reduce overall meat or dairy intake tend to elicit more polarized responses (Andrews et al., 2025; Leroy et al., 2025). Some nutritionists raise valid concerns about micronutrient deficiencies, particularly for vulnerable populations, urging caution in calls for reduced meat consumption. Yet these concerns are often entangled with narratives shaped by actors whose interests align with the meat industry, blurring the line between scientific caution and economic self-interest (Bryant et al., 2024; Krattenmacher et al., 2024). In practice, this often results in the dismissal or dilution of even moderate calls for reduced meat despite clear evidence that such reductions would yield health and environmental benefits for most of the population. This dynamic is not accidental; it reflects the disproportionate influence of meat and dairy sectors in shaping both public discourse and policy, where their lobbying power tends to outweigh that of other scientific or public interest voices (Clapp et al., 2025).

The fragmented academic landscape on the protein transition is problematic for several reasons. First, it makes it difficult to articulate clear, yet nuanced messages about what kind of change we should be advocating for. Without a systemic approach to the protein transition, it becomes

challenging to address trade-offs or to move beyond one-size-fits-all recommendations. For instance, promoting monogastric over ruminant meat solely on the basis of climate efficiency overlooks broader food system considerations such as the ecological role of ruminants in maintaining permanent grasslands (Aguilera Nuñez et al., 2024), or the cultural and economic significance of traditional grazing systems in certain European regions (Bignal & McCracken, 2000). Yet acknowledging the ecological and cultural importance of ruminants does not justify maintaining current production levels (Resare Sahlin et al., 2024).

Second, it facilitates cherry-picking of evidence to support predetermined positions. For example, some actors argue against reducing meat consumption by selectively citing data on its nutritional benefits while ignoring broader environmental and equity concerns (Torpman & Röö, 2024). When scientific evidence is cherry-picked or deployed selectively, narratives become skewed, often favoring interests backed by political or financial power. As a result, science becomes a contested arena, where competing visions of change vie for legitimacy (Duluins, Cardinaals, Potter, Espinosa, Resare Sahlin, et al., 2025; Duluins & Baret, 2024b).

Third, this fragmentation can lead to policy contradictions that waste resources or reinforce the status quo. Rather than aligning efforts across domains, policies may work at cross-purposes. A notable case is the political focus on feed and meat self-sufficiency, often driven by fears that reducing domestic livestock production would merely shift environmental burdens abroad. As a result, policy efforts prioritize feed autonomy while sidestepping deeper questions about reducing livestock production and meat consumption for health and environmental reasons (Duluins & Baret, 2024b).

Ontological and epistemological divides

Another key reflection point of this thesis lies in fundamental differences between disciplines themselves. Across this thesis, it becomes evident that disciplines differ not only in focus (research object) but also in their ontological assumptions (what they consider to be true or real) and in their epistemological approaches (what counts as valid evidence and good science) (Moon & Blackman, 2014). For example, critical realist perspectives argue that the world has ontological depth: events arise from mechanisms embedded in structures, but their outcomes vary depending on geo-historical context, meaning causal relationships cannot be reduced to simple regularities claims (Cleaver & Tom, 2008). By contrast, much natural science implicitly assumes that stable, observable cause-and-effect relationships can be identified

through controlled experimentation and empirical measurement (Cleaver & Tom, 2008). These differences in ontological and epistemological assumptions are not just theoretical: they translate into divergent views on what counts as good research, whether generalizable laws, statistical regularities, or contextual narratives. Even within disciplines, publication standards and methodological gatekeeping (e.g., randomized control trials or quantitative thresholds) reinforce hierarchies of legitimacy and shape what is recognized as “high-quality” science. In the context of the protein transition, such divergent standards and assumptions can result in a “dialogue of the deaf,” where valuable insights remain unacknowledged or undervalued simply because they fall outside a discipline’s accepted framework. Beyond shaping what is considered credible knowledge, these differing ontologies and worldviews also influence policy models and associated actions, revealing divergent ways in which researchers and policymakers understand society, the economy, and food systems, ultimately determining the types of interventions pursued within the protein transition (Cleaver & Tom, 2008).

Constructive potential and ways forward

At the same time, the existence of diverse disciplinary perspectives and narratives should not be seen solely as a barrier. Different disciplinary approaches can illuminate specific aspects of complex systems more effectively. The coexistence of these perspectives can be constructive, especially in a transition that must remain adaptive to varied regional, ecological, and socio-economic contexts. The challenge is twofold. First, it involves integrating disciplinary insights within a systemic approach to ensure that different knowledge systems are connected and mutually informative rather than isolated and ignoring systemic effects such as feedback loops or trade-offs. Second, it requires acknowledging both the diversity of viewpoints and the power dynamics that influence which perspectives gain visibility, shape policy discussions, and attract resources.

Finally, this dissertation underscores that progress in the protein transition cannot rely on scientific evidence alone. While generating evidence remains essential, it must be accompanied by greater reflexivity about how that evidence is framed, communicated, and used in decision-making. The political and institutional conditions under which knowledge circulates shape which forms of evidence are heard, valued, or sidelined. Moreover, the transition depends on the active engagement of a diverse range of actors, including policymakers, industry stakeholders, civil society organizations, farmers, and consumers, whose interests, values, and practices influence

the pathways of change. Therefore, the challenge is not only to produce more evidence, but to develop institutional capacities that enable deliberation across competing knowledge systems, support the negotiation of trade-offs, and align scientific insights with meaningful political and societal action.

Reflecting conclusions

Based on these reflections, this chapter emphasized four main findings:

First, knowledge production, uptake, and use are shaped by significant power dynamics at the science-policy-industry interfaces. Dominant actors, whether from the public or private sector, exert considerable influence over research agendas, funding priorities, and prevailing narratives. As a result, the current framing of the protein transition often aligns with an innovation- and growth-driven paradigm, prioritizing technological alternatives to animal proteins while overlooking deeper structural challenges and systemic inequalities. Thereby, it would be naive to assume that simply improving coordination or adopting a more systemic approach to the protein transition will be sufficient to drive change; the power dynamics within academia and at its interfaces with policy and industry fundamentally shapes which research agendas, solutions, and transition pathways gain traction.

Second, fragmentation across academic disciplines risks neglecting broader systemic dynamics. Different disciplines not only emphasize distinct components of the system but also operate with fundamentally different ontologies and epistemologies. These differences shape what is considered valid evidence, which cause-effect relations are prioritized, and how interventions are conceptualized which can result in a dialogue on deaf, where key systemic dynamics may be overlooked.

Third, structural and symbolic lock-in reinforces dominant paradigms. Technological innovation pathways benefit from both institutional support (policy frameworks, funding, and market incentives) and cultural-symbolic appeal (novelty, lifestyle branding, and consumer excitement). In contrast, sufficiency-based approaches face barriers in legitimacy, visibility, and desirability, creating a dual lock-in effect that favors efficiency- and growth-oriented transition pathways. Yet, these paradigms need not be mutually exclusive; reframing efficiency within a sufficiency paradigm could help redirect innovation toward genuine sustainability rather than continued expansion.

Fourth, the challenge lies not only in producing more evidence, but in understanding how such evidence can more effectively catalyze transformative change amid power dynamics and in response to growing calls for inter- and transdisciplinary approaches to address the multiple crises of the Anthropocene, including the food system crisis.

Building on these reflections, the next chapter turns to the fourth and final conclusion: how scientific evidence can more effectively inform political agendas and support transformative change.

Chapter 5: Momentum for transformative change: rethinking the role of science

In the face of growing challenges such as biodiversity loss, climate change, or the syndemic crisis of obesity, calls for transformative change in food systems have intensified (Bandola-Gill, 2023; Gurung et al., 2025; Marciniak et al., 2024; Sarkki et al., 2025). The protein transition is no exception. One key insight of this PhD is that responding to such global challenges requires not only more evidence but also a better understanding of how existing knowledge can more effectively inform political agendas and drive action (Bai et al., 2016; Benton, 2023; Duluins, Cardinaals, Potter, Espinosa, Resare Sahlin, et al., 2025; Fischer et al., 2024; Sarkki et al., 2025). The central challenge lies in clarifying the role of researchers in sustainability transitions: should they act as knowledge brokers, translating insights into actionable solutions, or should they embrace a more disruptive role, problematizing assumptions, questioning taken-for-granted cause-effect relations, and exposing the blind spots and normative choices that shape science and policy?

The role of transformative change in sustainability transitions

Transformative change has been defined as “a fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values” (IPBES, 2019). Transformative change is not only about incremental improvements or optimizing isolated elements, but about rethinking and restructuring systems at their roots, including their dominant views (ways of seeing things), structures (ways of organizing, regulating and governing) and practices (ways of doing, behaving and relating) (Gurung et al., 2025).

Two complementary understandings of transformative change inform this work. First, Stirling's (2015) underscores the political and contested nature of these processes, describing transformations as “emergent and unruly political re-alignments” driven by diverse, often conflicting knowledges and interests. Second, the IPBES (2019) definition stresses the scale and depth of transformation as a system-wide reorganization across social, technological, and economic structures, including norms, paradigms, and value systems. Together, these perspectives highlight that transformation is not only structural but also epistemic and normative.

One critical domain where such change is urgently needed is food system, which encompasses interconnected actors, institutions, infrastructures, cultural norms, technologies, rules, and activities that shape how food is produced, distributed, and consumed. These components interact to generate a wide range of outcomes within systems whose boundaries are politically and socially constructed (Ericksen, 2008; HLPE, 2017).

In the context of the protein transition, this raises two core concerns.

First, enabling transformative change requires a genuinely systemic approach reconnecting domains such as health, food production and consumption, and trade. The way the boundaries of food systems are drawn influences what is considered relevant and actionable. At present, these boundaries are often defined in ways that reproduce fragmentation. For instance, within the European Commission, food related issues are split across separate Directorates-General (DGs) including DG AGRI (agriculture), DG SANTE (health), DG TRADE, and DG ENV (environment), each with its own institutional logic, priorities, and blind spots (European Environment Agency, 2023). This fragmentation can to some extent undermine policy coherence and result in policy contradictions. For instance, health-oriented efforts to reduce red meat consumption (European Commission, 2020) may be counteracted by agricultural subsidies that continue to favor livestock production (Guyomard et al., 2021). In the case of protein transition, this disconnection plays out in the misalignment between consumption and health priorities on one side, and production and export strategies on the other. Addressing this tension could benefit from an institutional mechanism, such as a cross-DG working group, tasked with testing and improving the overall coherence of EU food policies.

Second, enabling transformative change involves rethinking the practice and role of science. This research is situated within the paradigm of transformative science, which engages with the ambition to accompany and support transformative change. Transformative science calls on researchers to actively interrogate assumptions, reflect on framings, and contribute to the co-production of knowledge that can inform just and sustainable futures (Marciniak et al., 2024; Sarkki et al., 2025), aligning with Cleaver & Tom (2008) notion of “reflexive knowledge”. Consequently, transformative sustainability science carries a normative responsibility to promote equitable and inclusive futures (Marciniak et al., 2024). It goes beyond generating knowledge about potential pathways, calling for active participation in shaping and implementing these

pathways through a reflexive, engaged, and ethically grounded scientific practice (Benton, 2023; Marciniak et al., 2024).

Rethinking the practice and role of science: Transformative science

This PhD engaged with new modes of science that have emerged in response to increasingly complex societal challenges—particularly in the domain of sustainability transitions. Building on concepts such as *Post-Normal Science* and *Mode-2 Science*²⁶ (Funtowicz & Ravetz, 1993; Nowotny et al., 2001), it adopted *transformative science* as both a conceptual lens and a methodological commitment. Transformative science is understood here as a mode of research that not only studies societal change but actively seeks to initiate and shape it (Marciniak et al., 2024; Sarkki et al., 2025). This approach positions science as a co-actor in of transformative change, particularly in contexts of sustainability transitions, where values, power relations, and knowledge systems are deeply contested.

Within this framework, the PhD made four key contributions to the understanding and practice of transformative science.

First, it defined and unpacked the multiple and sometimes competing meanings of the “protein transition” in scientific literature, revealing how terminology can define the perception of problems and narrow the scope of options envisioned as acceptable and desirable (Duluins, Cardinaals, Potter, Espinosa, Resare Sahlin, et al., 2025; Duluins & Baret, 2024a).

Second, it adopted a reflexive stance on scientific practice itself. It interrogated how disciplinary traditions shape the study of the protein transition, highlighting how ontological and epistemological assumptions influence not only what is considered valid knowledge, but also the questions asked, methods employed, and interpretations generated (Duluins & Baret, 2025).

Third, it questions the taken-for-granted cause-effect relationships often examined in disciplinary silos, by resituating them within a broader systems perspective (Duluins & Baret, 2024b).

²⁶ *Post-Normal Science* (PNS) refers to a mode of inquiry appropriate for situations where “facts are uncertain, values in dispute, stakes high, and decisions urgent” (Funtowicz & Ravetz, 1993). It challenges the conventional boundaries of scientific practice by emphasizing the inclusion of extended peer communities, reflexivity, and the co-production of knowledge in decision-making under conditions of uncertainty. *Mode-2 Science*, as proposed by Nowotny et al. (2001), similarly denotes a shift from traditional, disciplinary, and hierarchical knowledge production (*Mode-1*) to a more transdisciplinary, socially embedded, and context-driven form of research. Both concepts highlight the need for science to be adaptive, participatory, and responsive to real-world complexities, particularly in domains like sustainability, where normative considerations and stakeholder engagement are central.

Fourth, the research re-examined how scientific findings were framed, interpreted, or selectively mobilized to support specific political or economic agendas (Duluins, Cardinaals, Potter, Espinosa, Resare Sahlin, et al., 2025; Duluins & Baret, 2024b). It scrutinized how narratives could lend credibility to certain framings and pieces of evidence while marginalizing others., influenced by power dynamics at the science-policy-industry interface

This research thus proposes to contribute to transformative science by combining analytical depth with epistemic reflexivity and normative engagement. It illustrates how science can both shape and be shaped by societal transformations, and how researchers can engage in that co-evolution notably by taking on roles such as problem definers, solution co-creators, and narrative ambassadors.

The interplay between structures, views and practices

Building on the IPBES framework of transformative change, which identifies three interconnected dimensions (structures, practices, and views) (Figure 13), provides a useful lens for analyzing how systemic transformation unfolds (Gurung et al., 2025).

The Structures, represented at the bottom of the iceberg (Figure 13), refer to the institutional and systemic frameworks that set the conditions for change. In the context of the protein transition, these include agricultural policies (e.g., the Common Agricultural Policy, Nitrates Directive), research funding programs (e.g., Horizon Europe), and market infrastructures (e.g. supply chains, distribution networks, processing facilities, logistics). Regulatory standards, intellectual property regimes, and global trade agreements also shape which protein innovations can scale and succeed within the system, and which food products are prioritized in global markets. For example, trade agreements can affect the import and export of animal proteins like beef and poultry, while regulations influence the approval and commercialization of alternative proteins such as cultured meat (e.g. EU Novel Food Regulation (EU) 2015/2283).

Values and Views, represented at the apex of the Iceberg (Figure 13), refer to the underlying beliefs and cultural norms that support the entire system. These include dominant perceptions of what it means to be a livestock farmer or a scientist in Europe, the widespread belief that innovation must be technological and market-driven, entrenched models of economic growth, and normative ideas about what constitutes a healthy diet. For instance, in many European countries, meat consumption is deeply tied to identity, tradition, and social status, making the transition toward alternative proteins culturally sensitive. Resistance to reducing meat intake

often stems not only from dietary habits (Practices), but also from strong attachments to personal freedom, culinary heritage, and widespread skepticism toward novel protein sources like lab-grown meat or insects (Values and Views).

Practices encompass all the daily activities and interactions that both influence and are influenced by these structures and values and views (Figure 13). This encompasses farming or production methods, policymaking processes, consumer behaviors but also scientific practices.

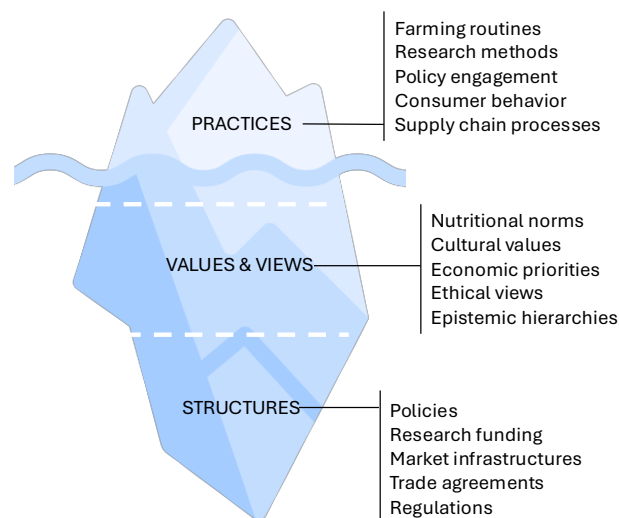


Figure 13: Structures, practices and values applied to the protein transition context (inspired by Gunrung et al. 2025 and the management iceberg model)

This PhD posits that practices are deeply embedded in, and shaped by, existing structures. In the case of the protein transition, these structures not only correspond to market-logics that condition food practices, but also the associated disciplines –meaning the scientific knowledge, technical standards, and regulatory norms that organize and legitimize these markets.

Focusing first on the relationship between practices and structures, it becomes clear that everyday practices, how food is produced, processed, consumed, or disposed of, are conditioned and stabilized over time by structural arrangements such as regulatory frameworks, policy incentives, market logics, and infrastructures. A prime example is the European Union’s Common Agricultural Policy (CAP), which, since the 1960s, has significantly shaped agricultural production systems. By providing price supports, subsidies, and market protections, the CAP favored livestock and cereal production, thereby encouraging high-output livestock farming and

creating structural disincentives for protein crop cultivation (Guyomard et al., 2021; Zander et al., 2016). Consumer habits also responded to structural shifts. Rising postwar incomes, the emergence of supermarkets, and convenient packaging made meat more accessible, while policies further enabled this trend by lowering feed costs and shielding domestic producers with tariffs and export subsidies (Belcher, 2006; Gardner, 1996; Popkin, 2006). Another key example concerns food environments, which are shaped by factors such as procurement policies, labeling regulations, and advertising practices (Djojosoeparto et al., 2024; SAPEA, 2023). These elements influence which proteins are accessible, affordable, and culturally desirable (Chungchunlam & Moughan, 2024; SAPEA, 2023). In this way, structural conditions define the boundaries of what is materially possible, socially acceptable, and economically viable.

At a deeper level, structural configurations are sustained by dominant worldviews. For instance, the persistent hegemony of economic growth as a central goal continues to shape European protein production systems. Europe remains the world's largest exporter of livestock products, with sectors like pork production heavily oriented toward export performance (Guyomard et al., 2021). This export-oriented logic is often justified on climate grounds: proponents argue that halting European production would shift it to regions with less climate-efficient systems (European Court of Auditors, 2021). In this way, dominant worldviews reinforce existing structures, which in turn shape the practices of livestock farming—often in ways that exceed the control or agency of individual actors (Cleaver & Tom, 2008).

In sum, this thesis highlights a paradox: although practices occupy a central place in current scientific and policy debates, they represent a limited entry point for pursuing transformative change. Practices are not free-floating; they are shaped, constrained, and stabilized by underlying structures and dominant values and views. While shifts in practice can act as catalysts, their transformative potential depends on whether they are reinforced by structural reforms and aligned with deeper value and worldview changes. Transformative change thus requires a systemic approach that acknowledges and works across the dynamic interplay between structures, values and views, and practices.

Recognizing the interdependence of structures, practices, and values and views underscores the need for interventions that engage with the institutional²⁷ and epistemic²⁸ structures that shape food systems. Among the most powerful levers for influencing these foundations is science itself, particularly through its interactions with policy. Through its role in framing problems, legitimizing solutions, and informing governance, science has the potential to reshape structural conditions and influence dominant worldviews. Yet this potential is mediated by how science is organized, practiced, and embedded within political processes, but also by underlying power dynamics that determine whose knowledge counts and which solutions are prioritized. While the role of power is acknowledged as critical, the following sections examine two critical dimensions of this dynamic: first, how science-policy interfaces (SPIs) act as sites of structural negotiation and political influence, and second, how science must reimagine its own role to more effectively contribute to transformative change.

Science-policy interfaces as drivers of structural change

If structures, such as policies, institutions, and market frameworks, stabilize or transform food systems, understanding and potentially influencing these structures becomes a central concern of scientific inquiry. This PhD contends that scientific activity does not merely serve to observe or critique; it is embedded in political and institutional contexts that contribute to shaping structural change (Benton, 2023). One key site where this structuring role becomes visible is the science-policy interface, where knowledge production, normative frameworks, and policy agendas intersect (Turnhout et al., 2021).

Science-policy interfaces (SPIs) are formal and informal arenas where knowledge meets political decision-making (van den Hove, 2007). These sites are not neutral; they are shaped by institutional norms, power asymmetries, and differing logics of action (Cleaver & Tom, 2008). Yet, they also offer key leverage points for shifting food system trajectories. Through these interfaces,

²⁷ Institutional structures refer to the formal and informal rules, norms, organizations, and power relations that shape how systems operate—in this case, food systems. These include government bodies, regulatory frameworks, market mechanisms, and policy-making processes that influence what actions are possible and how decisions are made.

²⁸ Epistemic structures relate to the ways knowledge is produced, validated, and shared. They involve dominant scientific paradigms, research methods, disciplinary boundaries, and the criteria for what counts as credible or legitimate knowledge. These structures influence which perspectives are prioritized or marginalized in understanding and addressing food system challenges.

science contributes to framing societal challenges, legitimizing certain pathways, and expanding or narrowing the space of political possibility (Benton, 2023; Turnhout, 2018).

This PhD engaged directly with these dynamics, analyzing how the framing of the “protein transition” influences policy directions (Duluins & Baret, 2024a), and how narratives grounded in selective evidence can reinforce the status quo in policy arenas (Duluins & Baret, 2024b). Through close interaction with institutional actors—such as DG AGRI, the Institute for European Environmental Policy (IEEP), and contributors to EU-level strategies like the Farm to Fork Strategy and the EU Protein Strategy—this research revealed how scientific input is mediated, translated, and constrained by political feasibility. For instance, informal exchanges with policymakers shed light on the political unviability of certain tools (e.g. meat taxation), insights often absent from formal documentation. Of course, a different focus could have been chosen for this PhD—one that might have more quickly led to conclusions about institutional resistance or policy inertia. However, this research intentionally remained open and engaged with the protein transition as a complex, multi-dimensional concept. The political context was treated not as the sole object of study, but as one interacting component within a broader socio-technological system shaped by scientific narratives, economic interests, cultural values, and ecological constraints.

This work thus repositioned science not as a passive conveyor of “evidence-based” solutions, but as an active participant in shaping the institutional and epistemic structures of food systems (Benton, 2023; Nowotny et al., 2001). It showed how structural leverage is gained not only through academic publication but also through iterative and situated engagement with policy actors, processes, and logics. Critically, it emphasized that knowledge must be made politically relevant without being politically captured—a delicate balance requiring reflexivity, adaptability, and strategic framing (Cleaver & Tom, 2008).

At their best, SPIs can support reflexive governance as structures capable of learning and evolving in response to uncertainty and multiple stakeholder needs (Levin et al., 2013). But this requires deliberate attention to the institutional conditions that support pluralism, deliberation, and long-term collaboration (Bammer et al., 2013). When these conditions are absent, science-policy interfaces risk reinforcing dominant paradigms, sidelining alternative knowledges, and undermining the very structural transformations they seek to inform (Hajer & Wagenaar, 2003).

Reimagining the role of science in transformative change

Structural transformation of food systems also demands a critical revision of science itself, including its values, practices, and organizational logics. Much of the difficulty in aligning science with transformative change stems from the way science is structured, practiced, and rewarded (Salmela et al., 2025). Interdisciplinary collaboration, for example, is often hailed as essential for sustainability, yet remains difficult to realize due to entrenched disciplinary boundaries and institutional inertia (Salmela et al., 2025; Whitley et al., 2022).

This PhD foregrounds the need to rethink science as a socially and politically situated practice (Jasanoff, 2004). It argues that interdisciplinarity requires more than methodological integration, it involves renegotiating legitimacy, authority, and purpose across epistemic communities (Jasanoff, 2004). Some disciplines, particularly those associated with quantitative data or economic modelling, continue to dominate policy spaces, while others, such as qualitative or experiential knowledges, remain marginal (Benton, 2023). These hierarchies shape whose knowledge counts in defining food system problems and designing solutions.

Moreover, it requires acknowledging that power dynamics are also embedded within academic institutions themselves. Hierarchies of disciplines, funding structures, and publication norms shape which research questions are pursued, which methodologies are legitimized, and which voices gain visibility. These internal academic power structures influence not only the production of knowledge but also the framing of problems, the identification of solutions, and the perceived credibility of different epistemic communities. Without attention to these dynamics, efforts of interdisciplinarity risk reproducing the same inequalities they aim to transcend, privileging dominant paradigms and limiting the potential for genuinely transformative insights.

This research took a pragmatist stance: disciplines were treated not as static repositories of truth, but as evolving communities of practices. Collaboration, from this perspective, is not about consensus from the outset but about shared inquiry grounded in real-world stakes. This view emphasizes that interdisciplinarity is not just a cognitive or technical task—it is a relational and ethical one, requiring trust, reflexivity, and attentiveness to power dynamics.

Furthermore, the PhD showed that engaging with policy is not a downstream application of upstream knowledge. Rather, it is a recursive process in which policy needs shape research agendas, and research strategies reshape what becomes possible in the policy arena. A key insight is that effective engagement depends on cultivating shared visions across disciplines—

alignment not just around methods, but around transformative intent. Without this alignment, even technically robust research risks becoming fragmented, misaligned, or politically inert.

In sum, structural change cannot be driven by policy shifts alone. It also requires science to examine its own role in stabilizing or transforming dominant paradigms and narratives. This entails rethinking the purpose of research, investing in collaborative capacities, and embracing science as a participatory, value-driven, and action-oriented enterprise. From this perspective, the protein transition is not just a matter of dietary and technological substitution, but a site for reimagining how knowledge is produced, mobilized, and made transformative.

Perspectives

This PhD journey does not conclude with definitive answers but with generative tensions that invite further exploration. The first concerns the future of science itself: should transformative science imply incremental training in systems thinking and interdisciplinarity, or does it require a more profound reconfiguration of academic institutions—their incentive structures, funding logics, and disciplinary boundaries? At stake is whether science will primarily serve existing political agendas, align with societal demands, or carve out an autonomous space for critical reflection and innovation.

A second tension lies in the origins of change: can transformative shifts in science emerge from within academia, despite its current entanglement with neoliberal logics of competition and productivity, or must they be catalyzed by external pressures, from policymakers, social movements, or wider societal expectations?

Finally, these reflections raise a more fundamental dilemma about governance in sustainability transitions: to what extent can such transitions be managed at all? Perhaps the challenge lies less in prediction and control than in navigating uncertainty, plurality, and surprise. For researchers and policymakers alike, this means reimagining their roles—not as sole architects of transformation, but as facilitators of conditions in which diverse pathways toward more just and sustainable futures can emerge.

Key questions for stakeholders to reflect upon at the conclusion of this PhD

For policymakers

- How should science be organized and funded to support not only technological innovation but also systemic and reflexive perspectives and disciplines?
- What institutional conditions are needed to enable a plurality of scientific roles, while avoiding the co-option of science by narrow economic or political agendas?
- How can policymaking processes remain open to diverse disciplinary contributions, including those that challenge dominant framings?

For scientists

- What does it mean to practice transformative science in concrete terms?
- Should science primarily serve as a problem-solving tool for policy, as a space for critical reflection, or as a mediator between competing societal demands?
- To what extent is reflexivity enough to reorient scientific practice, and where might structural reforms (e.g., interdisciplinarity, problem-oriented organization) be required?
- How can scientists navigate the tension between disciplinary traditions and the need for systemic, interdisciplinary perspectives?

For early-career researchers

- What kinds of training (systems thinking, interdisciplinarity, reflexivity) are necessary to engage meaningfully with sustainability transitions?
- How can young researchers position themselves in relation to dominant disciplinary and institutional logics without losing sight of alternative perspectives?
- What strategies are available to balance career demands (funding, publications, metrics) with a commitment to broader transformative agendas?

When doing research

- Have I considered and challenged the systemic dimension of my research?
- How does my disciplinary background shape the way I frame the problem, select methods, and interpret results?
- How might other disciplines approach the same research question, and what alternative perspectives could they bring?

- If I situate my research within a broader system, where do I draw the boundaries? What elements am I including, and what am I leaving out? Could aspects excluded from my system be central in other studies, and how does that affect my understanding?

This chapter argued that transformative change in food systems requires systemic reconfigurations of structures, practices, and underlying worldviews. In the case of the protein transition, it highlighted how institutional fragmentation, entrenched paradigms, and selective framings of science constrain ambition, while also pointing to openings for greater policy coherence and reflexive governance.

It further repositioned science from a neutral evidence-provider to an active co-actor in transformation, framing problems, legitimizing solutions, and shaping political possibility. Adopting transformative science as both lens and practice, this PhD underscored the need for reflexivity, interdisciplinarity, and critical engagement with power at the science-policy interface.

Ultimately, the chapter concludes that science carries a normative responsibility: not only to analyze possible pathways, but also to help shape more equitable and sustainable futures.

While the questions outlined above encourage deeper reflexivity among diverse actors within the system, I wanted to conclude this PhD by granting myself permission to ask: *What if I were in charge? What if change were possible? What would be needed?* The following section, therefore, offers an initial reflection on a utopian vision for reimagining future food systems.

Utopian vision for rethinking future food systems

The overarching goal of this vision is to create a food system where ecological limits, social equity, and human well-being guide every decision. In this system, science, policy, and citizen engagement form a mutually reinforcing loop, enabling systemic transformation across governance levels, and through a coordinated action plan.

This vision is underpinned by several key principles. First, it emphasizes ecological and social boundaries over economic growth: societal values are reconceptualized to prioritize adherence to ecological and social limits rather than the pursuit of material accumulation. This entails reducing excess consumption and resource extraction while maintaining well-being, thereby reframing the notion of societal progress from quantitative expansion to qualitative flourishing, including health, equity and ecological resilience. Second, it recognizes the plurality of knowledge, advocating for interdisciplinary, reflexive, and socially engaged scientific practices that bridge the gap between theoretical knowledge and actionable insights. This principle extends beyond academia, recognizing the value of diverse forms of knowledge, including local, indigenous, and experiential perspectives, that are often marginalized in conventional research and policymaking. Third, governance is democratized, incorporating citizens, communities, and diverse stakeholders into policy design processes, ensuring that food systems are socially legitimate and owned. Fourth, it demands reflexive institutions: universities, funding bodies, and research councils must be assessed not only on revenue streams or publication counts but also on their contribution to societal challenges, their support for interdisciplinary collaboration, and their ability to foster transformative change.

Transformative interventions begin with the institutional restructuring of scientific research. Universities and research councils are reconceptualized to embed interdisciplinary, problem-oriented, and reflexive structures, with reward systems that prioritize research addressing systemic challenges rather than research focusing solely on technological innovation or traditional academic outputs, such as publications in disciplinary or specialized journals. Reflexivity is systematically integrated into curricula through dedicated courses that encourage students, researchers, and professors to critically examine the ontological and epistemological foundations of their respective disciplines, while also situating knowledge within broader systemic contexts. Furthermore, new educational programs modeled on environmental or transition studies are designed to equip students with the skills to navigate multiple disciplinary

perspectives, fostering the capacity to address complex sustainability challenges in a holistic and socially engaged manner. Importantly, the persistence of disciplines themselves becomes an object of open societal debate: which disciplines should evolve, disappear, or emerge is not determined solely within academia but collectively deliberated in light of broader societal needs and sustainability imperatives.

Governance structures are reconceived to prioritize long-term strategic planning aligned with sustainability imperatives, thereby addressing the temporal misalignment between short-term electoral cycles and the enduring demands of systemic transitions. Central to this approach is the development of phased transition plans that provide continuity, direction, and adaptability over time. Policy instruments are thus deployed progressively, ensuring that change is both socially acceptable and politically feasible, while maintaining momentum toward transformative goals. In the case of a protein transition, such a strategy might unfold in multiple phases. In the context of a protein transition, an initial phase could require public institutions to ensure that at least one-third of menu options are vegetarian, reduce subsidies for animal products by 50%, introduce subsidies for plant-based proteins, and implement public campaigns promoting healthy and sustainable diets. Subsequent phases might involve banning promotions of animal products, formally recognizing producers of plant-based proteins, and ultimately eliminating all meat subsidies. A final stage could include the targeted reduction of livestock populations in ecologically sensitive regions, identified through prior assessment, accompanied by support mechanisms to assist affected farmers in transitioning to alternative livelihoods.

Citizen engagement is integral to this framework. Too often, participatory approaches are designed in a top-down fashion, where institutions invite citizens into pre-defined consultation processes with limited influence on decision-making. By contrast, a transformative approach requires rethinking governance structures to enable bottom-up forms of participation, where citizens, communities, and social movements play a proactive role in defining the problems, setting priorities, and shaping solutions for food systems. Such an approach not only supports collective initiatives driving dietary shifts, resource sufficiency, and equitable protein systems, but also enables the co-production of narratives and metrics of progress that extend beyond conventional economic indicators such as GDP.

Scientific research assumes a genuinely co-constructive role, shaping both the political feasibility and social acceptability of proposed interventions, while also drawing its research questions from the needs and concerns articulated within society. Interdisciplinary events and fora at the

interface of science, civil society, and policymaking further strengthen collaborative capacities and reflexivity, explicitly interrogating normative assumptions, such as the persistent equation of growth with progress. In this way, transformative science seeks to balance epistemic rigor with societal relevance, bridging evidence and values while ensuring that its agenda remains responsive to democratic priorities and public needs.

Cultural and narrative transformation reinforces systemic change. Conceptualizations of success are reframed to emphasize ecological resilience, social equity, and human flourishing. Practices oriented toward sufficiency and regeneration are normalized as aspirational rather than restrictive. Storytelling, media, and educational interventions are employed strategically to cultivate systemic thinking and collective responsibility.

In a utopian scenario, (protein) food systems prioritize environmental sustainability, social justice, and public health. Technological innovation is pursued selectively, contingent on its contribution to systemic goals rather than as a substitute for structural transformation. Universities and research institutions actively facilitate interdisciplinary and transformative research agendas, while citizens engage meaningfully in policy co-creation, fostering shared ownership of sustainability objectives. Collectively, these elements constitute a food system capable of sustaining ecological integrity, promoting social equity, and enhancing human well-being.

Chapter 6: Reflecting on the journey

This chapter offers a personal reflection on the intellectual and personal journey of my PhD, a path that has led me from bioengineering, through agricultural economics, to the broader and often unsettling terrain of interdisciplinary sustainability science. It has been a journey marked by curiosity, discomfort, questioning, and gradual transformation, both in how I see the world and how I position myself within it, as a human and citizen, and as a researcher.

From forests to food systems: A shifting identity

My academic background is in bioengineering, with a specialization in the management of forests and natural areas. Early in my PhD, I made a deliberate choice to orient my work around a concept, the protein transition, rather than entering a concept through a single disciplinary lens. This decision shaped the trajectory of the entire thesis, as the complexity of the subject required engagement with multiple disciplines.

What began as a desire to understand the protein transition in all its dimensions led me to immerse myself in a wide array of disciplinary literatures. My goal was not to master each discipline, but to develop a conceptual and analytical vocabulary broad enough to ask meaningful, cross-cutting questions. The first outcome of this process was the **Narrative Paper** (Paper 1), which drew on diverse epistemologies and cross-disciplinary insights.

Throughout the PhD, I continued to explore a wide range of perspectives, from the political economy of meat and the nutritional implications of consuming different protein sources to the subsidy structures of the Common Agricultural Policy (CAP), the concept of "less but better" meat consumption, and consumer preferences across protein sources. This interdisciplinary approach has remained central to my research and critical to understanding the complexity and contested nature of the protein transition.

Belonging nowhere, and everywhere

Throughout the PhD, I often grappled with the question of disciplinary identity. Scientists are frequently introduced, or introduce themselves, by their field: "economist", "ecologist", "political scientist". In my case, although I was trained as a bioengineer, I increasingly felt that this background alone was not enough to fully engage with the complexity of the questions I was exploring. I recognized an opportunity to expand my perspective and engage with other

academic disciplines, embracing the idea that each discipline and its methods serve as valuable tools for tackling complex questions.

This interdisciplinary posture has often felt both delicate and vulnerable. A particularly defining moment occurred during a postdoctoral interview, when I was asked: *“So, you’re a bioengineer and you don’t perform experiments? What exactly is it that you do, then?”* That question captured the ongoing difficulty of articulating a role that does not fit neatly within traditional disciplinary expectations. It surfaced the persistent challenge of making visible the often-invisible labor of translation, coordination, and synthesis—work that is essential to cross-disciplinary collaboration, but frequently marginalized or undervalued in academia, especially for young scientists.

Much of the discomfort I experienced—of not knowing enough, of not feeling legitimate, of wondering whether I was contributing anything meaningful—stemmed (at least partly) from this disciplinary in-betweenness. I now see that these moments were not failures, but openings: what Chadwick (2021) describes as “resistance to the reiteration of comfortable and normative truths”. These discomforts nudged me to reflect, question, and ultimately expand my understanding of what it means to do science today.

Learning through engagement

My thinking was shaped not only by literature, but by people. I participated in over 20 conferences, workshops, and summer schools—each a unique encounter with scholars and practitioners working on food systems, agroecology, nutrition, and sustainability at large. This social and intellectual immersion helped me build a community around the concepts of “protein transition” and “livestock transition,” and brought my attention to the pluralism of knowledge systems at play.

However, not anchoring my research within one discipline, with predefined research questions or methods, meant living with a tension. This tension was not only intellectual but also social, as I moved across disciplinary communities and their rituals, from conferences to workshops, each with its own expectations, languages, and ways of legitimizing knowledge. On the one hand, this allowed for integrative thinking. On the other, it meant I was rarely “at home” in any academic space. Yet over time, this position at the margins became a strength. It gave me the agility to connect dots across fields, and to recognize the value of thinking with, rather than against, disciplinary boundaries.

Interrogating science itself

This PhD has also been a reflection on science: how it is practiced, structured, and disseminated. I realized that our current research system, built on disciplinary silos and metrics of specialization, is poorly equipped to tackle complex, systemic issues like the protein transition. This thesis does not offer grand solutions, but it does invite a different way of asking questions—one that is slower, more integrative, and more open to uncertainty.

It also highlights that science is not neutral. Each discipline carries implicit assumptions, values, and interpretive frameworks that shape how problems are framed and what solutions are deemed acceptable. The Restatement Paper and the Disciplinary Paper made this explicit, drawing attention to how narratives and framings shape what is seen and what remains invisible in sustainability debates. Notably, discussions of non-neutrality are often immediately associated with vested interests, ethical stakes, or conflicting interests, phenomena typically framed as ethically problematic and unacceptable. By contrast, epistemic non-neutrality, which is pervasive within scientific practice, pertains less to ethical transgression than to reflexivity: the capacity of researchers to critically examine their own positionality, assumptions, and the epistemic lenses through which knowledge is produced.

In many ways, this PhD became as much a reflection on the role of the scientist as it was about the topic itself. Understanding, coordinating, and facilitating interactions across disciplines are essential skills for addressing complex global issues. And yet, these roles remain poorly recognized in traditional academic settings. By engaging with different disciplines, ontologies, and epistemologies, this research underscores that knowledge production is not only analytical—it is political, relational, and transformative. Even within theoretical frameworks, how we build and communicate knowledge can shape discourse, influence imaginaries, and contribute to science-based change-making.

Sobriety as common sense

If, at times, I have felt like I have not “invented” anything in this thesis, it is perhaps because most of the insights seem so rooted in common sense. Why keep designing consumption-driven solutions when overconsumption is the problem?

This work is, at heart, a plea for sufficiency, not only as a behavioral choice, but as a principle for rethinking our food systems. It is a call to shift focus from individual responsibility to institutional

capacity, from market logic to public imagination. Sufficiency here is not about restriction, but about coherence: aligning our goals, policies, and practices with ecological and social realities.

Writing a thesis that seeks to articulate what sometimes feels “simply obvious” has been a humbling experience. It has required learning that the value of research does not always lie in proposing novel solutions or providing empirical evidence, but sometimes in asking the right questions that unsettle dominant narratives and expose the assumptions underpinning them. The work, then, becomes not one of invention, but of clarification, connection, and interrogation.

Staying with the questions

This thesis is a work of understanding. It has sought to unpack a concept, the protein transition, by tracing its multiple meanings across disciplines, its role in shaping policy and industry narratives, and its potential to either reinforce or challenge existing food system dynamics.

It has also been an exercise in staying with the questions, especially those that resist easy answers:

- What is the role of a scientist in pursuing transformative change?
- How do we contribute to systemic transitions when our tools are built for compartmentalized problems?
- What futures are being imagined, by whom and for whom?

I do not have final answers to these questions. But I have learned that curiosity, discomfort, and dialogue are not obstacles—they are the very conditions for meaningful inquiry.

A researcher in transition

Becoming a sustainability scientist did not happen all at once. It emerged slowly, through doubts, conversations, readings, frustrations, and moments of clarity. It emerged in the space between disciplines, in the courage to sit with uncertainty, and in the humility to accept that progress often looks like circling back to what seems “obvious” and asking why we have ignored it.

This thesis is not a blueprint. It is a contribution to an ongoing conversation about food systems, science, transitions, and the kind of futures we dare to imagine. It is also a quiet invitation to reimagine the role of the scientist: not as an isolated expert, but as a connector, a questioner, and a participant in collective processes of change.

Chapter 7: Conclusions

This PhD has examined the concept of the protein transition, analyzing how it is conceptualized and addressed within the scientific literature, with particular emphasis on the role of science in shaping and enabling broader food system transformations. To guide this inquiry, I posed three interrelated research questions: 1) What are the meanings and functions of the protein transition in the context of food system sustainability?; 2) What are the diverse disciplinary perspectives to the protein transition, and how are they integrated in a holistic vision?; 3) What types of solutions and transition pathways for action are currently proposed, and how coherent and relevant are they to the complex systemic challenges at stake?

Each paper contributed a different lens through which to examine these questions. The Narrative Paper explored the diverse meanings and roles the protein transition plays in relation to food system sustainability, offering foundational insights into the multiplicity of narratives of the protein transition in scientific literature. The Shadow Paper investigated how protein transition narratives are intertwined with livestock sustainability debates, bridging production and consumption dimensions. The Discipline Paper provided an analysis of the disciplinary contributions to the protein transition, highlighting the barriers and opportunities for greater academic integration and a more systemic vision. The Restatement Paper represented a collaborative effort to bridge disciplinary divides by synthesizing insights from environmental science, nutrition, economics, and policy studies into a coherent, policy-relevant overview of the protein transition. It also underscored the need for greater epistemological and ontological reflexivity to navigate the fragmented evidence base and foster a more holistic approach to the protein transition. The Paradox Paper interrogated solutionism in the protein transition, revealing that while many solutions appear effective when considered in isolation, their integration to the broader food system often reveals persistent problems: root causes remain unaddressed, and interventions can inadvertently reinforce the very structures they aim to transform.

This thesis engaged in a dynamic process of theorizing and critical re-examination. It actively assembled diverse insights into coherent causal explanations aimed not only at describing the world but also to illuminate potential pathways for change: both those to pursue and those to avoid. At the same time, it deconstructed and contextualized causal-effect relationships by situating them within broader systemic, institutional, and socio-political dynamics. Through critical engagement with dominant narratives, power structures, and institutional framings, the

thesis generated prescriptive insights into how science and policy can more effectively support meaningful food system transformation.

Three overarching conclusions can be drawn at the end of this PhD:

First, the protein transition is most commonly defined as a dietary shift in which animal proteins are replaced with “alternatives”. While this definition provides a clear entry point, it also reveals the limitations of prevailing approaches, which often frame the transition primarily as a question of technological substitution rather than as a broader endeavor of systemic transformation within food systems. This thesis argues that such a narrow emphasis on product replacement risks diluting the concept’s transformative potential by leaving unexamined the deeper structures, paradigms, and power structures that shape how food is produced, consumed, and socially valued. This substitution logic reinforces existing industrial, efficiency-driven, and growth-oriented paradigms, merely adapting new products to old systems. It does not disrupt the economic rationales, institutional arrangements, or political interests that shape our food systems. In contrast, shifting from a protein transition to a protein transformation would require a substitution of models, replacing the dominant logic of extractive, growth-maximizing food systems with ones rooted in sufficiency paradigms, social and environmental justice, and democratic participation. Such a transformation entails rethinking structures, values and views as well as practices, while also interrogating whose interests are served, whose knowledge counts, and what futures are made possible or foreclosed by dominant framings. Crucially, this also requires addressing what may be considered the “elephant in the room”: the persistent growth-centric paradigm that continues to underpin institutions, policies, and scientific agendas, and that constrains the political and cultural imagination of more sustainable and equitable alternatives.

Second, this research highlights the evolving role of science in the context of sustainability transitions. In the face of escalating ecological and social crises, science can no longer remain a neutral observer or a mere supplier of technological fixes. Instead, it must become reflexive, engaged, and politically aware, capable of grappling with uncertainty, conflict, and complexity. This demands a shift from producing data toward rethinking how problems are defined and how solutions are (co-)constructed. It involves embracing plural forms of knowledge, fostering inter and transdisciplinary collaboration that transcends academic silos, and acknowledging the normative dimensions of sustainability research. A transformative science must ask not only “what works,” but also “for whom,” “in what context,” and “with what consequences”. Crucially,

this also entails a profound re-examination of how science itself is organized. Current scientific institutions remain deeply embedded in the growth-centric paradigm, with incentive structures tied to competition, productivity metrics, and siloed disciplines. Furthermore, science continues to be predominantly shaped by Western epistemologies, privileging the authority of scientific expertise while marginalizing other knowledge systems. It also remains heavily dominated by technological approaches, which often perpetuate the very paradigms they claim to solve.

Third, the thesis underscores the risk of solutions when these are treated as substitutes for systemic change and fail to engage with their broader impact within food systems. In practice, many current strategies are well-intentioned but incoherent, addressing one problem while exacerbating others or delivering only marginal gains. Moving forward with protein transition must ensure that options are; 1) relevant, i.e., clearly targeting well-defined challenges; 2) coherent, i.e., aligned across scales and domains, without creating unintended trade-offs, and 3) and impactful, i.e., capable of delivering change at the scale and magnitude required. This calls for evaluating the systemic interactions among interventions and their cumulative potential to reshape food systems rather than simply refine them. Coherence and impact also depend on looking beyond individual behaviors or technologies to consider the institutional, economic, and structural forces that enable or constrain transitions.

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